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Reducing Back Injuries in Low-Coal Mines: Redesign of Materials-Handling Tasks

By Sean Gallagher, Thomas G. Bobick,
and Richard L. Unger

U.S. DEPARTMENT OF THE INTERIOR ★ BUREAU OF MINES ★ 80 YEARS

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb	pound
h	hour	L/min	liter per minute
in	inch	min	minute
kcal/min	kilocalorie per minute	pct	percent

REDUCING BACK INJURIES IN LOW-COAL MINES: REDESIGN OF MATERIALS-HANDLING TASKS

By Sean Gallagher,[1] Thomas G. Bobick,[2] and Richard L. Unger[3]

ABSTRACT

This report describes research by the Bureau of Mines on alternative materials-handling strategies for reducing the costs and incidence of back injuries in low-seam coal mines. Strategies recommended for redesigning materials-handling tasks include elimination of tasks, mechanization of tasks, and matching lifting tasks to the physical capabilities of underground miners. The report also discusses other methods that can be used by management to reduce the costs associated with back injuries.

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INTRODUCTION

Low-back pain is the most common cause of occupational disability in the U.S. underground coal mining industry. In fact, approximately 25 pct of injuries in underground coal mines involve trauma to the back. These injuries represent the leading cause of lost workdays in underground mines and typically account for 30 to 40 pct of worker compensation payments made by the industry. A large portion of these injuries (estimated at about 35 pct) are related to manual handling of supplies, parts, and equipment (*1*).[4]

Table 1 illustrates the costs of coal mining back injuries from 1981 through 1986. These data are based on accident records contained in the U.S. Mine Safety and Health Administration (MSHA) data base, analyzed using the Bureau of Mines Accident Cost Indicator Model (ACIM). According to ACIM, the estimated cost of back injuries in coal mining for 1981-86 was over $100 million. This estimate should be viewed as a conservative figure because, in addition to the costs estimated in table 1, there may be other so-called hidden costs, such as costs of training new workers, administrative costs, legal fees, and so forth, that may drive the total cost of these injuries still higher. The data presented here clearly demonstrate that traditional methods of preventing back injuries (for example, worker training) have had limited success, and that new and innovative approaches of controlling the problem of back injuries in the mining industry are needed.

Table 1.–Estimated cost of back injuries (million dollars) in coal mining industry during the years 1981-86

Year	Cost to–			Total cost
	Industry	Family	Public	
1981	12.5	5.7	2.1	20.3
1982	12.6	5.1	.6	18.3
1983	8.7	3.9	.6	13.2
1984	9.9	4.4	.6	14.9
1985	14.6	5.9	3.0	23.5
1986	10.1	6.2	.4	16.7

Source: MSHA data base, using Bureau's ACIM.

PREVENTION OF BACK INJURIES IN LOW-COAL MINES

The underground low-coal mining environment presents some unique barriers to preventing back injuries (*2*). The restricted roof height of low-coal mines (seam thickness of less than or equal to 48 in) forces miners to adopt stressful working postures during manual materials-handling activities. Miners generally stoop and kneel when lifting in low-seam mines. Both postures cause a considerable amount of stress on the spine and may account for the high incidence of low-back pain in the coal mining industry. The confined workspace of low-seam mines makes the use of certain types of mechanical-assist devices more difficult. In addition, the problems of poor illumination and slippery work conditions may compound the problems associated with manual materials-handling underground.

The traditional approach to reducing the risk of back injuries has been to train miners to cope with the existing work conditions. Unfortunately, this method is very limited in terms of effectiveness (*3*). In recent years, a much more constructive method of preventing back injuries has evolved, called ergonomic redesign of the workplace. It has dramatically reduced both the incidence and cost associated with low-back pain in many industries. Simply stated, ergonomics is a science that strives to match the demands of a job to the worker's capability to perform the job. Too often, workers must perform tasks that exceed their capabilities. When this happens, the risk of injury to the worker is great. Matching the job demand to the worker's capability reduces the risk of injury. Workers may also interact more effectively with the working environment. In addition, certain modifications in the way a job is performed (and often these can be quite simple) can significantly lessen a worker's chances of sustaining an injury.

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH) WORK PRACTICES GUIDE FOR MANUAL LIFTING

In 1981, the National Institute for Occupational Safety and Health (NIOSH) developed a "Work Practices Guide for Manual Lifting" (*4*). The work practices guide summarizes a vast amount of research related to the biomechanical, physiological, and psychophysical stresses associated with manual lifting. This Guide presents quantitative recommendations for establishing safe load limits based upon factors such as the size of the load, the frequency of lifting, and the location of the load at the start and end of the lift. The Guide also presents recommendations regarding worker strength capabilities, worker training, and physical fitness, as well as specific engineering guidelines for the design of workplaces. The mine safety and health professional who is serious about reducing injuries due to manual materials-handling is encouraged to study this document.

Unfortunately, the recommendations contained in the NIOSH Guide are somewhat limited in terms of applicability to the underground mining environment (particularly low-seam mines). The lifting limits in the Guide assume the worker is lifting in an unrestricted working posture, lifting directly in front of the body without twisting. Additionally, the limits apply only to lifting situations having good couplings (for example, handles on boxes and dry floor surfaces). Unfortunately, many lifting tasks performed in low-seam coal mines violate many (if not all) of these assumptions. For this reason, the Bureau has undertaken to examine the unique problems associated with manual materials-handling in underground mines and to develop recommendations for ergonomic redesign of

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[4]Italic numbers in parentheses refer to items in the list of references at the end of this report.

lifting tasks in the restricted low-seam coal mining environment. This work was done in support of the Bureau's program to enhance the health and safety of mine workers.

MODEL FOR REDESIGN OF UNDERGROUND MATERIALS-HANDLING TASKS

Figure 1 presents a model that can assist in the redesign of materials-handling tasks in low-seam coal mines. This model outlines the sequence of steps that should be followed (and questions that should be asked) when determining alternative materials-handling strategies in low-seam coal mines. This figure, which summarizes the materials-handling redesign strategies advocated by the Bureau, is referred to throughout this report.

The ensuing chapters discuss the various components of the task redesign procedure. Chapter 1 of this report describes methods by which a mine's current supply-handling system can be analyzed both to identify favorable aspects of prevailing procedures and, more importantly, to detect materials-handling problem areas. The two most effective redesign strategies, elimination of unnecessary manual lifting and mechanization of materials-handling tasks, are discussed in chapter 2. Chapter 3 presents results of Bureau research demonstrating how lifting capacity is reduced in the restricted postures often used in low-seam mines and discusses redesigning underground manual lifting tasks according to the physical capabilities of the worker. Examples of redesign techniques are contained in chapter 4. The role of management in reducing disability due to back injuries is contained in chapter 5. Finally, a review of recommended practices for handling materials in low-seam coal mines is presented in chapter 6. Proper application of the redesign techniques contained in this report may be very helpful in controlling the costs of back injuries experienced in low-seam mines.

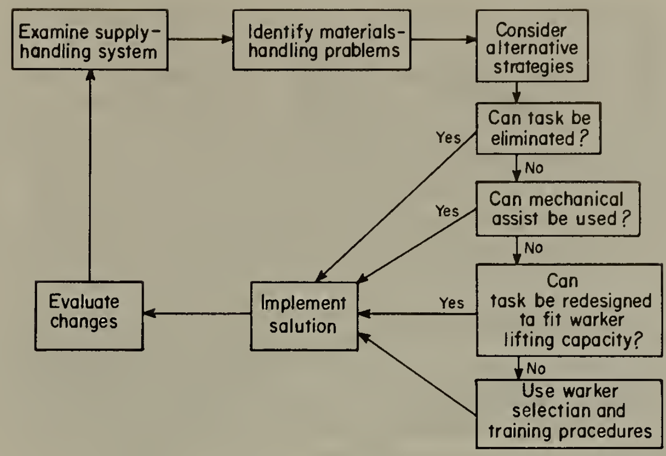

Figure 1.–A model for redesigning materials-handling tasks.

CHAPTER 1.–IDENTIFYING MATERIALS-HANDLING PROBLEMS

The techniques for handling items in the underground workplace, whether manually or mechanically, can vary extensively depending on the environmental factors of the mine, available equipment to assist in moving items, and current management practices. Unfortunately, many supplies and heavy equipment components are still routinely handled manually in underground coal mines. Identifying problems or bottlenecks in existing materials-handling systems can lead to a reduction in the number of times that supplies have to be handled manually (through the redesign techniques discussed in later chapters), and this process should ultimately diminish the chance that workers will experience a low-back injury (or any other musculoskeletal injury).

Important aspects of analyzing the current supply-handling system include reviewing past accident statistics, observing the problem jobs or areas in the workplace, interviewing the involved workers, and considering alternative procedures to the existing materials-handling system. Figure 2 provides a flowchart to help identify specific materials-handling problems. The various components of this flowchart are discussed throughout this chapter.

REVIEW OF ACCIDENT STATISTICS

Company Accident Records

The goal of the accident analysis is to identify activities that lead to injuries so that such injuries can be prevented in the future. An analysis of past accident records will help pinpoint the occupations and the activities that have contributed to both lost-time and non-lost-time accidents. A comprehensive analysis of the accident reports should be performed to identify the physical conditions, body postures, and work activities of injured workers at the time of injury. The occupations or materials-handling activities associated with high injury rates will, of course, be the prime candidates for job redesign.

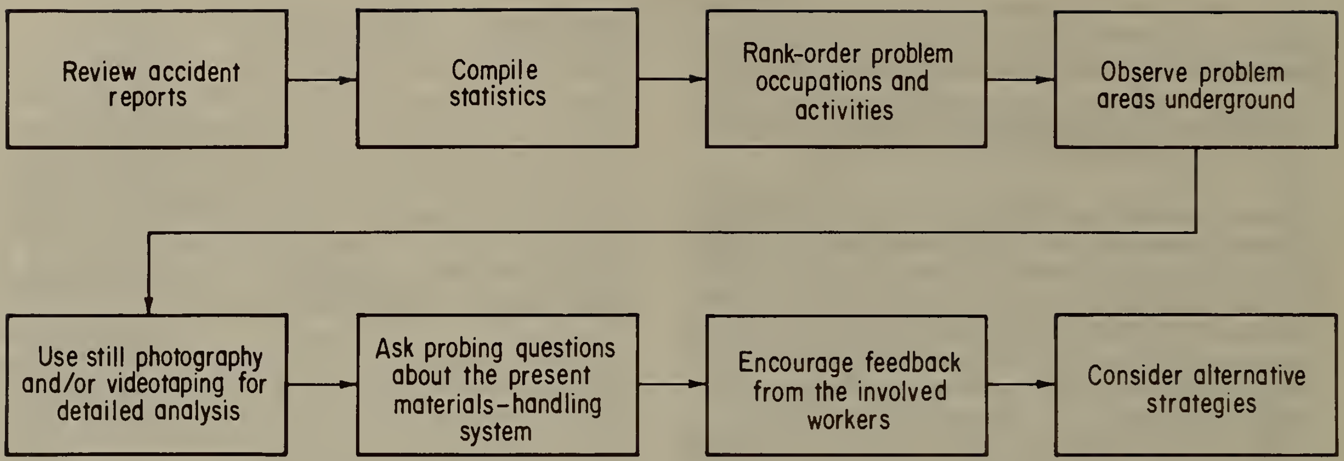

Figure 2.–Method for identifying hazardous materials-handling tasks.

The compilation of accident statistics and the estimate of injury potential can be used to rank-order the occupations and the job duties that have caused problems when materials are handled or moved. An example of an accident analysis, contained in tables 2 and 3, has identified the occupations and activities associated with back injuries at an underground coal mine. According to the accident data presented in table 2, the three jobs where most back injuries occurred were general laborer, maintenance mechanic, and roof bolt operator. These jobs should be carefully examined through a task analysis so that the materials-handling hazards associated with them can be identified. Once the hazardous activities of these jobs have been recognized, alternative materials-handling strategies can be developed.

Table 2.–Results of accident analysis examining occupations experiencing highest incidence of back injuries

Occupation	*pct of all back injuries*
General laborer	27
Maintenance mechanic	19
Roof bolter operator	15
Shuttle car operator	8
Conveyor belt operator	7
Supervisor	4
Electrician	4
Continuous miner operator	4
Other	12

Table 3.–Results of accident analysis relating to activities causing back injuries at an underground coal mine

Activity causing injury	*pct of all back injuries*
Materials handling	42
Equipment maintenance	18
Roof bolting	10
Operating shuttle car	5
Using prybar	4
Operating continuous miner	4
Shovelling	3
Other	14

The analysis of the activities that were responsible for the back injuries (table 3) indicates that materials-handling activities were the leading cause of back injuries, followed by equipment maintenance and roof bolting. These results are not surprising, because all of these activities require considerable heavy lifting and other physical exertion. Obviously, it is necessary to develop safer and more efficient methods of performing these hazardous tasks.

Another important aspect of the accident analysis is interviewing injured workers to gather more information about the causative factors of the injury than what is included in the usually brief accident description. During this dialogue, workers should be encouraged to suggest ideas they have for redesigning the workplace or changing the standard work procedure. Getting the employees to provide feedback promotes worker involvement in eliminating potential hazards.

Mine Safety and Health Administration (MSHA) Data Base

If the mine is relatively new and does not have 3 or 4 years of accident statistics to review, the MSHA data base of accidents can be utilized. This data base provides the total number of lost-time accidents, parts of body injured, causes of accidents, and activities at the time the injuries occurred, for all U.S. mines that reported injuries on the "Mine Accident, Injury and Illness Report" (MSHA form 7000-1). Thus, these data can be used to focus attention on jobs and activities that have contributed to lost-time accidents in other U.S. mines. This compiled information is available from MSHA in its ongoing series of reports entitled "Injury Experience in Coal Mining" (*5*).

TASK ANALYSIS

After the accident statistics are compiled and analyzed, problem areas in the mine should be visited to determine the hazardous conditions associated with performing specific mining jobs. A task or job analysis should be performed to identify the various factors that characterize the materials-handling situation. Such an analysis usually consists of a detailed listing of the job activities in a systematic order, generally in the sequence in which they occur in the job (*6*). The intent of the task analysis is to characterize the hazardous components of the job and the corresponding bodily actions or postures that are required to complete that job. The primary objective of the task analysis is to identify ways to reduce the number of times that items are manually handled. The more often supplies are manually handled, the greater the potential that a worker will experience a back injury. In addition, an increase in breakage and waste of materials is likely the more often these supplies are handled.

Equipment Needed for Task Analysis

Various types of equipment can be utilized to document the occupational demands and materials-handling activities present in the underground mining environment. Videotape, still photography, portable tape recorders, and taking notes are some of the best methods to document the entire job sequence. Videotape is the preferred recording system for a task analysis, because the analyst can watch the job being performed in "real" time. Videotape can also be reviewed and analyzed as many times as needed to provide information about the hazardous activities of that job. In addition, most videotape units allow the analyst to take verbal notes while videotaping. Figure 3 shows a Bureau researcher using videotape equipment while performing a task analysis underground that documented the movement of supplies and equipment parts.

Mines that may consider purchasing a videotape recording system to record activities underground should realize that additional lighting may be required for underground videotaping. However, low-light-level videotape sytems can also be purchased. Although they operate quite adequately close to the subject (5 to 8 ft), some extra lighting is usually required if the subject is 15 or 20 ft from the camera. An important consideration is the permissibility of the video system and the auxiliary lighting. Commercially available photographic products can be used underground in fresh air but, of course, cannot be taken beyond the last open crosscut. To determine the permissibility of equipment, the items in question need to be tested by MSHA's Approval and Certification Center, Triadelphia, WV. To videotape tasks such as installing temporary roof supports would require using a permissible system or, alternatively, posing those tasks for videotaping in another part of the mine that is in fresh air. A flash that is typically used with a still camera is nonpermissible. A permissible flash, however, is commercially available. This flash unit permits still photos to be collected of tasks that are conducted in the face area of the mining section. Those mines that do not have the resources to purchase a videotape recording system can use still photography and a handheld tape recorder to document the activities of a particular job. The tape recorder is a good way to compile notes and observations quickly and easily about the physical layout and environmental conditions of the sections visited during the task analysis.

Figure 3.–Bureau researcher performing underground task analysis.

Performing the Analysis

There are two primary approaches that can be used in a task analysis of the materials-handling problems in a mine. One approach is to examine the flow of supplies from the point of delivery to the point of end use. For example, one might record the current methods of transporting concrete blocks from the point of delivery on the surface to the actual building of the ventilation stopping underground. The task analysis videotape should document each step in the movement of these supplies from surface storage to end-use locations underground. The same procedure should be followed for all manner of supply items. The information collected in the task analysis can subsequently be analyzed to determine ways in which the supply-handling system can be made safer and more efficient.

The other approach is to examine the hazards associated with specific occupations. For example, if an accident analysis has shown that mechanics experience a significant number of lost-time injuries, the examiner would want to follow a mechanic throughout the working day to videotape the tasks required by the job. The analyst would want to distinguish the most hazardous tasks of this job and evaluate alternative methods (such as using mechanical-assist devices to aid in lifting tasks) that could reduce the hazards.

Analysis of Videotape and Photographic Data

As mentioned previously, one benefit of documenting tasks on videotape is that it can be reviewed as many times as necessary to determine an appropriate materials-handling solutions for hazardous tasks. Some experts in the field of task analysis feel that repeated viewing of a videotape of a particular task is very helpful in developing creative solutions as to how the job may be more safely or efficiently performed. It is often helpful to have two or more persons review the videotape so that the analysts can brainstorm methods for improving the current materials-handling methods.

As part of the process to eliminate or reduce manual handling of supplies and parts, the analyst should question all aspects of the supply-handling system. Consider an example: Suppose the task analysis videotape shows that considerable disorganization exists at the surface supply yard at a mine. What is the scope of the problem? Is it limited to the supply yard itself? Is it caused by inadequate on-site storage facilities, or is it caused by poor materials-handling practices? Could the problem be the way the materials are received from the suppliers? Can the schedule for delivery of supplies and equipment be more regimented, instead of being dependent on the supplier's schedule? Can the supplies be received in a different configuration (already on a pallet or banded together, instead of loose) to promote mechanical handling of materials?

The problem definition should contain quantitative information whenever possible. If there is a designated area for underground storage of parts or supplies, what are the dimensions of each storage compartment or area? How far away from the active face is it? How many different parts or supply items are stored there? How have materials been organized in the storage areas? Are the supplies organized before they are delivered to the production sections?

Generalized checklists, which help identify hazardous conditions and activities of typical materials-handling jobs, have been developed for the manufacturing industries. They are general enough so they can be used or easily modified for use in the underground mining industry. The checklist that follows can be a starting point to identify materials-handling problems in the underground workplace.

1. Crowded operating conditions.
2. Cluttered entries and supply areas.
3. Poor housekeeping.
4. Delays or backtracking in flow of supplies.
5. Obstacles in flow of materials.
6. Manual handling of loads weighing more than 45 lb.
7. Two-worker lifting jobs attempted by a single employee.
8. Excessive temporary storage.
9. Excessive time spent retrieving stored parts or supplies.
10. Excessive manual loading and unloading.
11. Single items handled instead of unit loads.
12. Excessive breakage of supplies or damaged parts.
13. Not utilizing materials-handling equipment when appropriate.

Although the checklist should not be relied upon exclusively to identify problems with the system, it may help to spot signs and symptoms that are associated with poor materials-handling practices.

Interviewing Workers

As with the accident analysis, an important aspect of the task analysis process is encouraging the workers to provide their observations and comments regarding any of the potentially hazardous areas or activities. The workers may have already tried to incorporate some sort of change to the workplace or to the work method to alleviate the hazardous condition or awkward posture. Getting feedback from the workers regarding their suggested modifications sometimes provides the analyst with the beginnings of a permanent solution for those situations.

Task Analysis Example

A comparison of two task analyses performed at underground coal mines by the Bureau can help to demonstrate the usefulness of documenting the current methods of supply-handling at the minesite. The first mining operation received its concrete ventilation blocks from the supplier in a loose configuration. The individual blocks were stacked onto the storage pile by the supplier. Similarly, the supply workers had to manually load the supply car with concrete blocks at the beginning of each shift. This required that each block be handled twice; the first time, workers removed a block from the storage pile and set it upright on the supply car, and the second time, they stacked the block neatly on its side so the load would clear a low spot along the main haulageway (fig. 4*A*). The blocks were handled a third time when they were unloaded in an underground storage area. When they were needed at a work location, the blocks were manually loaded (a fourth time) onto the top of a shuttle car or into the bucket of a scoop. If the scoop was used, the blocks could be mechanically unloaded with the hydraulically powered pusher plate. If a shuttle car was used, the blocks were manually unloaded at the work location. Thus, for this mine each concrete block was manually lifted a total of four or five times from when it left the surface storage area until it reached the location underground where the ventilation stopping was to be built.

In contrast, the second mining operation received its blocks banded together as a unit of 84 blocks. A forklift was used to load the units onto the supply car on the surface (fig. 4*B*). The supply car was then left at the operating section. When the blocks were needed, a chain was wrapped around the banded blocks and the pusher plate of a scoop was used to pull the unit load off the supply car. The scoop then delivered the blocks to the location where the ventilation stopping was to be constructed. This procedure eliminated all manual lifts except for the final placement of the blocks.

A typical ventilation stopping, which is 20 ft wide and 44 in high, requires 6 rows of block with 15 blocks to a row, or a total of 90 blocks. Compared with procedures used at the first workplace, up to 450 manual lifts have been eliminated per stopping by the mechanization procedure employed by at the second workplace and the risk of worker injury has been substantially reduced.

Figure 5 shows flowcharts, developed from the task analyses at these two mines, of the movement of the blocks from the surface storage area to their end-use location. Three modes of movement are shown. Manual transfer occurs when the supplies are moved manually with support, such as when a miner manually drags a block to the edge of the supply car. Manual transport is unsupported movement of the supplies, such as lifting a block from the surface storage pile and stacking it on the supply car, or lifting a block from the supply car and stacking it on the underground storage pile. Mechanical transfer or transport includes any handling of supplies or material conducted entirely by mechanical means. An example of mechanical transfer would be using a chain and the pusher plate of a scoop to drag or push a unit load of blocks off the supply car; an example of a mechanical transport is using a scoop to move the blocks to the work area where the ventilation stopping is to be built.

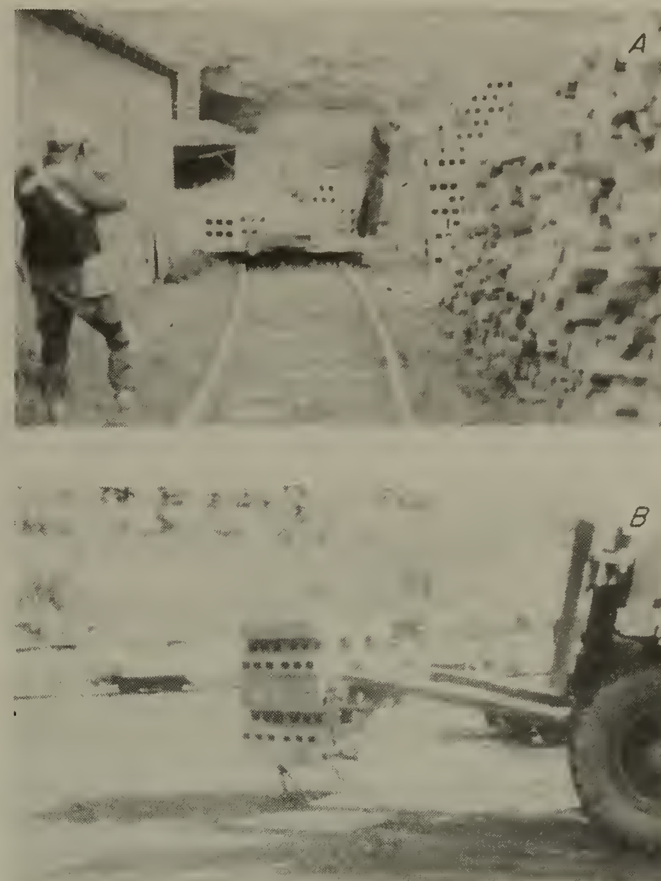

Figure 4.–Concrete block handling. *A*, **Loading blocks at mine A required hundreds of lifts;** *B*, **mine B received blocks banded together so that they could be loaded mechanically.**

The flowchart of the concrete block movement at mine A indicates that the blocks are being handled unnecessarily many times before reaching their final location. The flowchart of the same activity at mine B shows that all manual handling has been eliminated, except for final placement of the blocks. This sort of flowchart can be a very useful tool for identifying problems with the current supply-handling system and tasks that can be redesigned to make the system safer and more efficient.

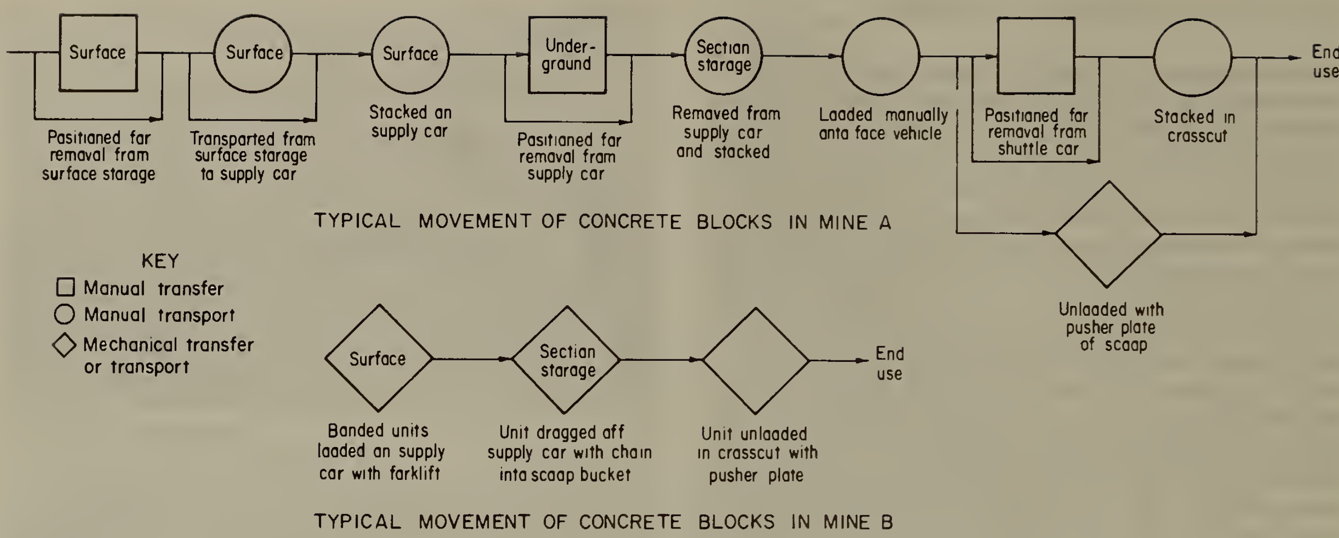

Figure 5.–Comparison of methods for transporting concrete blocks at two mines.

SUMMARY

This chapter has discussed the importance of identifying materials-handling problems specific to each workplace as the initial step in reducing injuries caused by handling materials. A review of past accident reports is necessary to identify problem areas. High-risk jobs and activities should be observed while they are performed. A task analysis can define the components of the job and identify hazardous procedures. Use of a videotape recorder, still photography, a handheld tape recorder, and the analyst's own notes will assist with a detailed analysis of job components. When the materials-handling system is examined, every aspect should be critically questioned. Just because a particular technique or method of operation has traditionally been used in a mine's supply-handling system does not mean that it is the safest or most efficient way to accomplish the movement of supplies and equipment. Equally important is the need to encourage the workers to provide their observations and comments regarding the supply-handling system. By considering input from all of these areas, alternative strategies can be developed and implemented. Subsequent chapters discuss methods of redesigning materials-handling tasks to reduce the risk of injury to the worker.

CHAPTER 2.–ELIMINATING AND MECHANIZING MATERIALS-HANDLING TASKS

Once a task analysis has identified potentially hazardous materials-handling problems, alternative strategies should be developed and implemented. As seen in figure 1, the two most desirable redesign strategies are elimination of the materials-handling task and the development and use of mechanical-assist devices to perform the task. This chapter presents ideas for reducing the amount of manual materials handling in underground coal mines using these two redesign strategies. Given that every mine is in some way unique, the specific examples may not work at every mine. However, the concepts presented, when correctly applied, are valid for most (if not all) mining operations.

ELIMINATION OF MATERIALS-HANDLING TASKS

Elimination of hazardous materials-handling tasks (especially manual tasks) is the best way to avoid injuries. Eliminating, reducing, or combining movements of supplies is often accomplished through the use of mechanical devices; however, materials-handling tasks can also be eliminated through better organization and planning of the supply-handling system.

The following are examples of the kinds of materials-handling problems that can be eliminated through the implementation of a well-designed supply-handling system.

Example 1

At one mining operation visited by the Bureau, a hazardous lifting task could have been eliminated through improving the organization of the surface storage area. At this mine, workers needed to salvage a 250-lb timber that would be used to help support the roof in a particular section of the mine. Unfortunately, the timber had been indiscriminately tossed into a junk pile for storage, an area that no mechanical-assist device could access. Although a forklift was brought over to the junk pile, it could not get close enough to reach the timber. Therefore, it was necessary for two workers to lift the timber manually onto the forks. Obviously, this hazardous manual lifting task could have been prevented simply by stacking the timber neatly in an area where the forklift could easily approach it so that it could be lifted entirely through mechanical means. As this example suggests, the surface supply yard is one area where it is relatively easy to use standard mechanical-assist devices. In fact, manual lifting should rarely have to take place in a well-designed surface supply yard.

Example 2

A materials-handling system can encompass an entire mine and may even extend to the facilities of the mine's suppliers. For example, at the mine, the system may begin at the surface supply area and continue through delivery to underground locations. But, if necessary, it can also include packaging and shipping operations at the supplier's plant. In fact, the manner in which supplies are received at the mine may determine the extent to which the supplies can be mechanically handled. For instance, the Bureau has observed some mines where supplies such as rock dust were delivered as hundreds of individual bags that had to be loaded manually onto supply cars. However, it would have been just as easy for the supplier to deliver these items either on pallets or banded in unit loads, which could then be loaded mechanically onto the supply car, thus eliminating hundreds of heavy manual lifts. The mine in this example had a forklift available that could perform the lifts mechanically; however, because the materials were not delivered to the mine in a suitable manner, the mechanical-assist device could not be used. Unfortunately, many examples of under-utilization of available mechanical-assist devices exist in the mining industry. The great majority of loading operations on the surface can be performed through mechanical means, using just a forklift or a front-end loader. Close communication with the mine's supplier is crucial in designing a supply-handling system that uses mechanical-assist devices to the fullest extent possible.

Example 3

One of the most common tasks in underground coal mining is lifting and securing power cables to the mine roof so that equipment may pass freely through the mine. A simple way to eliminate this strenuous lifting task is to use lightweight cable ramps; the cable can now remain on the mine floor and is protected from harm (fig. 6). This is a direct application of the simplification principle of materials handling.

A careful examination of the supply-handling system currently in operation at a mine will probably identify several materials-handling tasks that can be either eliminated, reduced, or combined to improve the flow of supplies. Eliminating these unnecessary tasks can both improve the economy of the supply-handling system and greatly reduce the risk of injury to workers.

USING TASK-SPECIFIC MECHANICAL-ASSIST DEVICES

If a materials-handling task cannot be eliminated, the next solution to consider is whether a task-specific mechanical-assist device can be used or developed to accomplish the task, rather than having the job performed manually. This section describes the redesign of materials-handling tasks through the use of mechanical-assist devices. Included is a summary of Bureau research that has demonstrated that easily fabricated mechanical devices can be developed to assist with many specific underground materials-handling tasks.

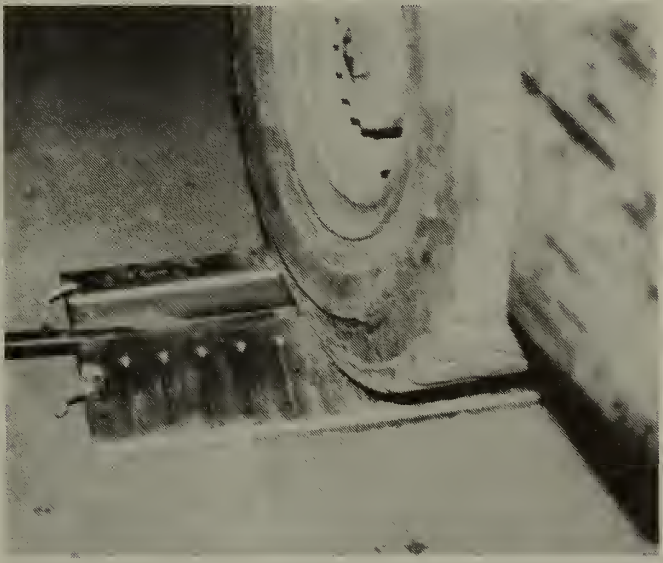

Figure 6.–Cable ramps eliminate manual lifting.

The previous section dealt with the steps to develop a system to handle the daily supply-handling needs in an underground coal mine. However, many of the more hazardous materials-handling activities occur during mine and equipment maintenance tasks (table 4), which are often performed infrequently. In its studies of the materials-handling problems in underground coal mines, the Bureau has concluded that these infrequent handling tasks are best addressed through the use of mine-specific materials-handling devices. "Mine-specific" means hardware tailored to the particular environmental and operating characteristics of the individual mine. Unfortunately, the Bureau has discovered a lack of mechanical handling devices suitable for the underground environment. Specifically, there are virtually no mechanical assists to aid in the end use of an item. Therefore, the Bureau began to specifically study materials-handling problems after supplies have been delivered underground and while they are being used during mine or machine maintenance. This research resulted in the categorizing of specific needs for underground materials-handling devices:

1. Devices to lift, lower, and rotate machine components (weighing up to 2,000 lb) that need to be removed or replaced on mining equipment.
2. Devices to lift or lower components up to 500 lb in and out of scoops and on and off railcars and other mobile vehicles.
3. Devices to remove palletized materials from railcars and to transport them to working sections or supply areas.
4. Devices to transport small quantities of materials weighing up to 500 lb from storage areas or rail headings to working sections.
5. Devices to lift long, slender loads of up to 600 lb for roof support in haulageways or other areas of the mine.

Table 4.–Hazardous mine and equipment maintenance tasks, 1980 data

Days lost	Activity	Unit weight, lb	Frequency
5,961 ..	Handling machine parts or tools.	5- 200	Weekly.
4,639 ..	Handling oil drums, grease cans, hydraulic oil.	5- 50	Daily.
3,753 ..	Handling cribbing, timber, props, and crossbars.	50- 500	Daily.
3,022 ..	Track maintenance	100-1,000	Monthly.
2,862 ..	Handling pumps, motors, gear boxes, wheel units, and other major components.	200-2,000	Monthly.
1,675 ..	Handling tires	50- 200	Weekly.

Once these needs were identified, work was started on the designing and testing of practical, low-cost, easily fabricated materials-handling devices that were broadly applicable to underground operations. Where possible, the designs were simplified and off-the-shelf components were used to permit easy fabrication and modification of the devices by mine personnel to suit specific needs.

Several task-specific mechanical-assist devices are pictured in figures 7 through 14, and are discussed below. Detailed plans for all of the devices are available through the Bureau (7). It is hoped that the simplicity and successful operation of this materials-handling hardware will inspire mine operators to investigate similar low-cost mechanical solutions for reducing manual materials handling in their mines.

Heavy-Component Lift-Transport

One identified need was for a floor-type maintenance jack that could lift heavy machine components from the floor, transport them over short distances, and raise them into position for installation on face equipment. This type of device could be used to install drive motors under the nonremovable panels on shuttle cars or to replace heavy tires underground.

The prototype of this device is pictured in figure 7. The device utilizes a hydraulic floor jack mechanism to provide the lift. The jackhead tilts and rotates to permit close-in maneuvering. The jack mechanism travels along the device frame by means of a sump drive mechanism. This motion permits forward-backward movement of the components and balancing over the wheels of the device during travel. The long handle permits the user to have leverage to maneuver loads up, down, or sideways as required. Dual tires or oversized balloon tires increase the device stability and permit easy movement over uneven ground conditions.

Beam-Raising Vehicle

Manually lifting heavy wooden crossbeams or sections of rail for roof support is one of the most hazardous tasks in underground mining. A device was needed that could raise long, slender members, weighing up to 600 lb, and hold them in place against the roof while permanent supports were installed.

The prototype device is pictured during an underground test (fig. 8). This device uses a modified automotive floor jack to provide the lift, while special bearings allow the whole jack mechanism to roll down the center of the car for positioning the load. The jackhead also rotates to make load positioning easier.

Scoop-Mounted Lift Boom

Figure 9 demonstrates a simple boom device that can be quickly mounted on the front of a small scoop after the bucket has been removed. This boom can lift and transport components weighing up to 3,000 lb, such as a continuous miner head. The scoop-mounted lift boom is a simple design that can be fabricated at the minesite and can be readily stored in working sections or on mobile machinery. This device can be installed or removed in 5 min or less.

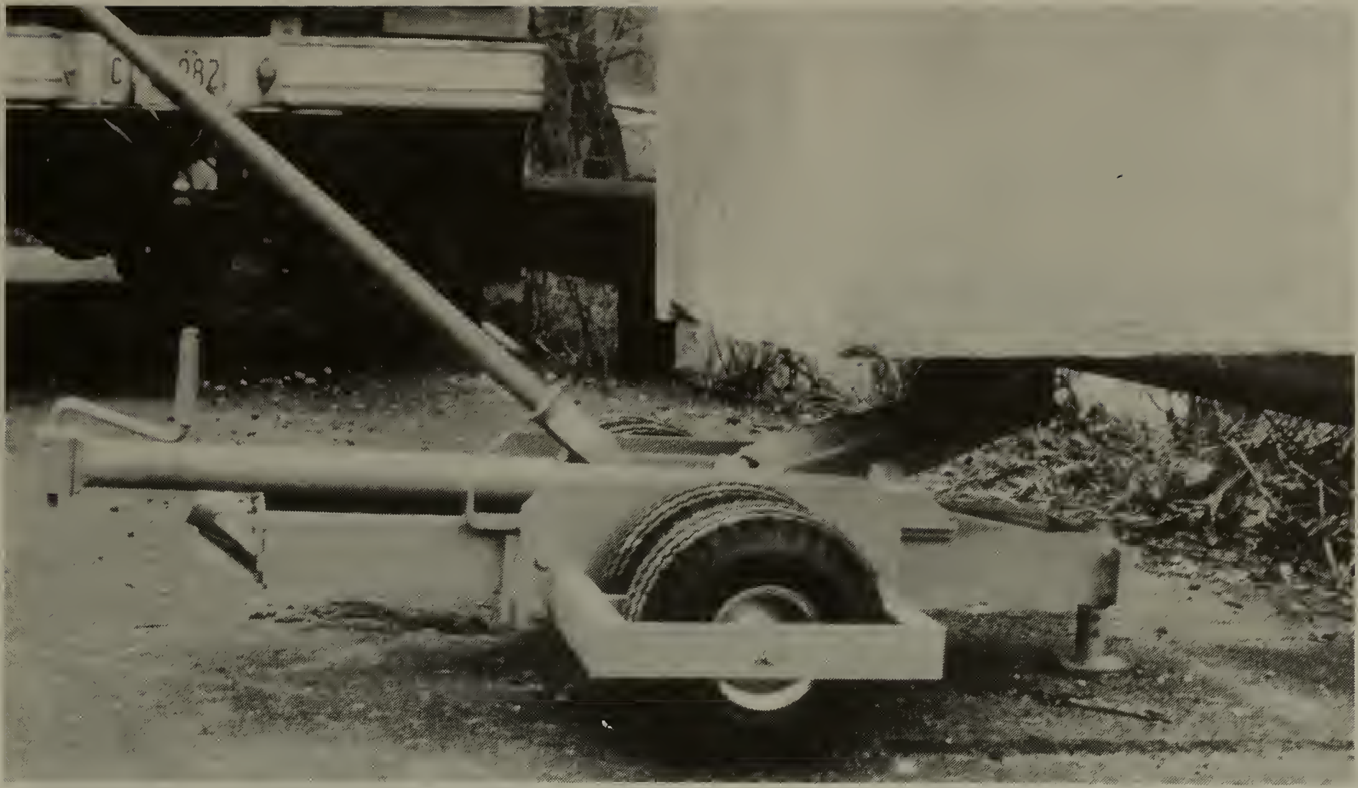

Figure 7.–Heavy-component lift-transport.

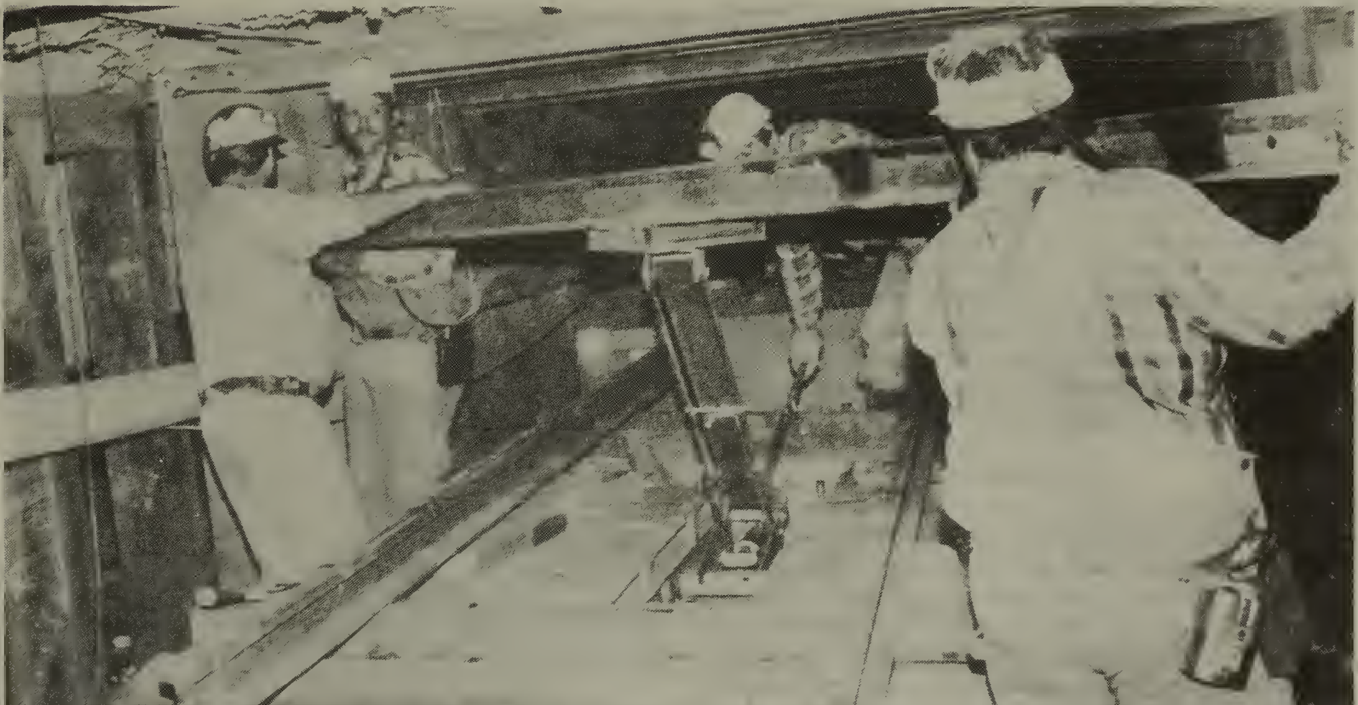

Figure 8.–Beam-raising vehicle.

Figure 9.–Scoop-mounted lift boom.

Machine-Mounted Swivel Crane

A lightweight, removable, and stowable lift crane is pictured in figures 10 and 11. This device can be installed on maintenance carts or on mining machines using inexpensive mounts welded permanently at various locations on the machine frame. The height of the crane can be quickly varied from 24 to 68 in by changing the crane leg; the arm radius is variable from 24 to 48 in. The machine-mounted swivel crane can lift components (up to 500 lb) on and off transport vehicles and maneuver heavy machine components in confined spaces. This device can be carried by one person, mounts and stows without tools, and can be fabricated in a mine shop.

Mine Mud Cart

Figure 12 demonstrates a small, manually pulled cart that can transport up to 900 lb of materials over a short distance. The mine mud cart features balloon tires for easy transit through mud or water and over mine floors. The narrow width of the vehicle permits passage by a parked mining machine, and the handle is designed for pulling by one or two people. This device can also be locally fabricated.

Container-Workstation Vehicle

Tools and supplies required for many maintenance tasks can be mounted in a transportable container, as pictured in figures 13 and 14. The transportable container may function as a tool station, lubrication module, rock dust unit, fire and safety equipment storage unit, cable splicing module, etc. The container-workstation vehicle allows for rapidly interchangable containers that can be picked up or dropped off as needed and can carry up to 1,000 lb. Other features include balloon tires for transportation on unimproved mine floor, adjustable ground clearance, and a towbar that can be adapted for towing behind utility vehicles. This device can also be fabricated in most mine shops.

SYSTEMS APPROACH TO MATERIALS HANDLING

As mentioned above, two alternative strategies include eliminating the task or utilizing mechanical-handling equipment to assist the workers. To the extent possible, these job redesign strategies should emphasize constructing an efficient and integrated materials-handling system–in other words, a systems approach to materials-handling.

Figure 10.–Installation of machine-mounted swivel crane.

Figure 11.–Machine-mounted swivel crane in use underground.

A systems approach to materials handling means that the various components for handling and storing supplies or components are integrated and considered as one entity, not just as a series of isolated steps haphazardly strung together. The systems methodology was originally applied to military and aerospace planning but recently has been used successfully in industrial materials handling. The same concepts are applicable to daily supply handling in the underground mining environment.

The following list summarizes the major benefits that can be achieved by applying a systems approach to materials handling in an underground mine:

1. Better coordination with suppliers and customers.
2. Fewer delays between mining operations.
3. Higher levels of equipment utilization.
4. Improved scheduling.
5. Less material loss due to breakage.
6. Lower labor costs.
7. Reduced materials storage requirements.
8. Safer, more systematic work procedures.

Increased safety is of particular concern in underground mining. As mentioned, almost 35 pct of all reported lost-time mining accidents annually can be attributed to manually handling parts, supplies, or equipment. These accidents usually involve lifting, lowering, pushing, pulling, and related types of effort. A supply-handling system that makes use of mechanization can play a leading role in reducing these injuries. The introduction of even simple, manually operated types of carts and hoists can go a long way toward providing a safer workplace. While a properly designed supply-handling system can improve the safety of operations, it is imperative that engineers and managers make sure that any new equipment introduced as a part of the system does not introduce new hazards to the workplace. Possible hazards should be investigated before any new materials-handling equipment is purchased or fabricated. Also, periodic inspections are an important part of any materials-handling safety program. Detailed inspection procedures and recommended frequencies are available from most equipment dealers and manufacturers.

There are many possible methods for handling materials at any given mine. It is good practice, therefore, to begin the development of a systems approach to materials handling by considering the 20 principles of materials handling (*8*):

1. **Orientation Principle:** Study the system relationships thoroughly prior to preliminary planning in order to identify existing methods and problems, physical and economic constraints, and future requirements.

2. **Planning Principle:** Establish a plan to include basic requirements, desirable options, and the consideration of contingencies for all materials-handling and storage activities.

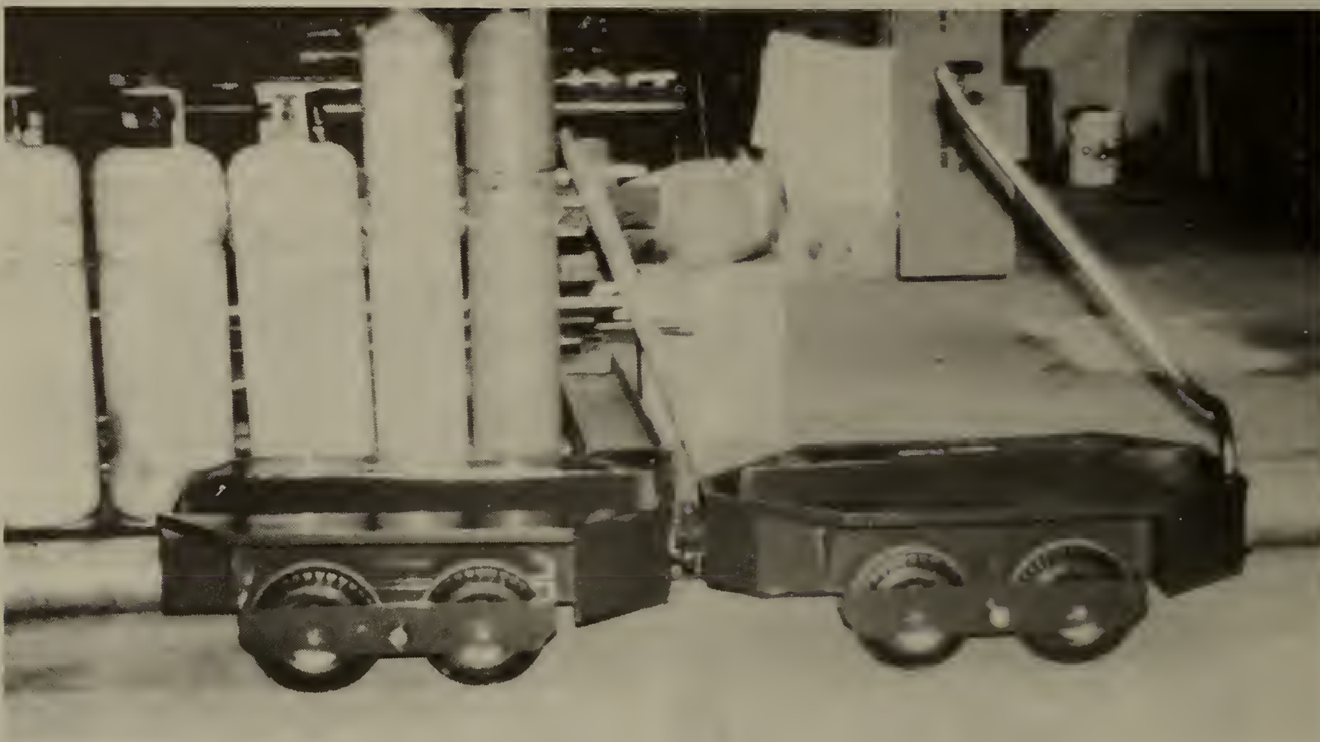

Figure 12.–Mine mud cart.

Figure 13.–Container-workstation vehicle.

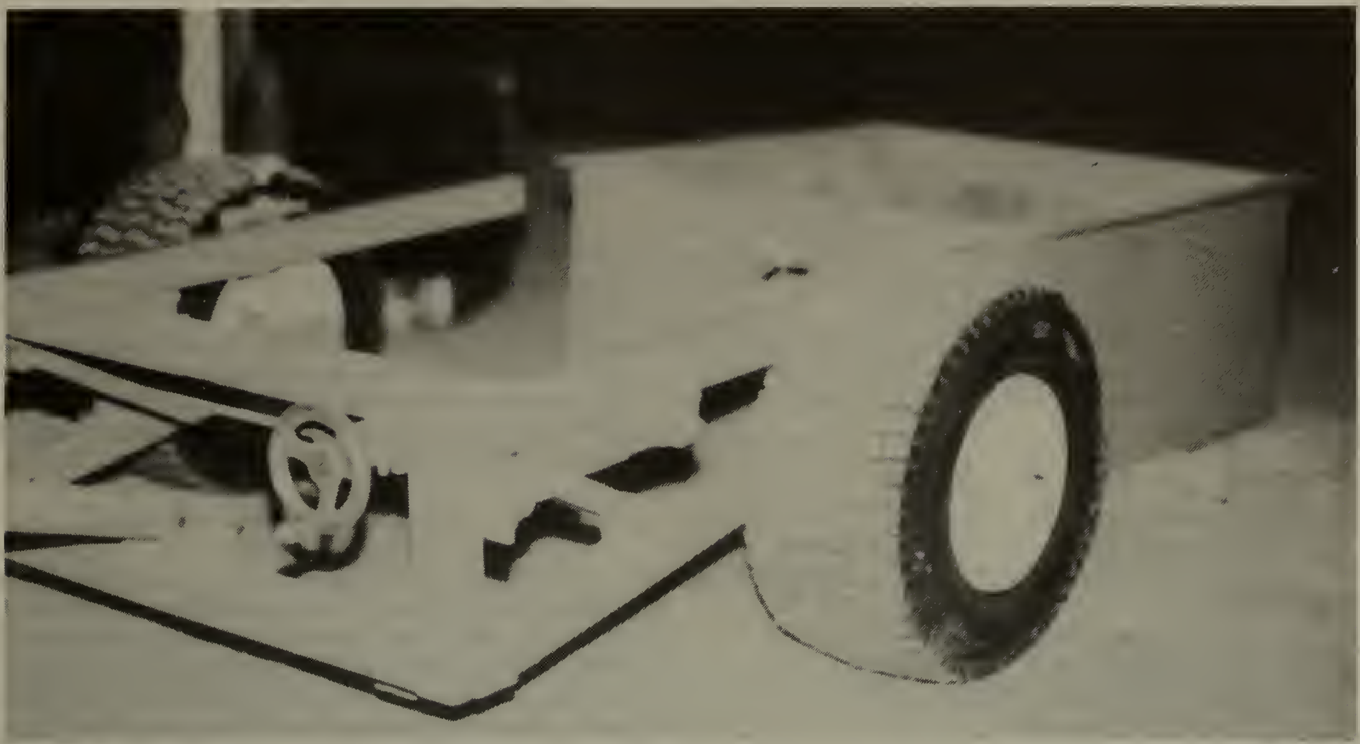

Figure 14.–Interchange of containers on container-workstation vehicle.

3. **Systems Principle:** Integrate those handling and storage activities that are economically viable into a coordinated system of operation including receiving, inspection, storage, production, assembly, packaging, warehousing, shipping, and transportation.

4. **Unit Load Principle:** Handle product in as large a unit load as practical.

5. **Space Utilization Principle:** Make effective utilization of all cubic space.

6. **Standardization Principle:** Standardize handling methods and equipment wherever possible.

7. **Ergonomic Principle:** Recognize human capabilities and limitations by designing materials-handling equipment and procedures for effective interaction with the people using the system.

8. **Energy Principle:** Include energy consumption of the materials-handling systems and materials-handling procedures when making comparisons or preparing economic justifications.

9. **Ecology Principle:** Minimize adverse effects on the environment when selecting materials-handling equipment and procedures.

10. **Mechanization Principle:** Mechanize the handling process where feasible to increase efficiency and economy in the handling of materials.

11. **Flexibility Principle:** Use methods and equipment that can perform a variety of tasks under a variety of operating conditions.

12. **Simplification Principle:** Simplify handling by eliminating, reducing, or combining unnecessary movements and equipment.

13. **Gravity Principle:** Utilize gravity to move material wherever possible while respecting limitations concerning safety product damage and loss.

14. **Safety Principle:** Provide safe material handling equipment and methods which follow existing safety codes and regulations in addition to accrued experience.

15. **Computerization Principle:** Consider computerization in materials-handling and storage systems when circumstances warrant, for improved material and information control.

16. **System Flow Principle:** Integrate data flow with the physical material flow in handling and storage.

17. **Layout Principle:** Prepare an operational sequence and equipment layout for all viable system solutions; then select the alternative system that best integrates efficiency and effectiveness.

18. **Cost Principle:** Compare the economic justification of alternative solutions in equipment and methods on the basis of economic effectiveness as measured by expense per unit handled.

19. **Maintenance Principle:** Prepare a plan for preventive maintenance and scheduled repairs on all materials-handling equipment.

20. **Obsolescence Principle:** Prepare a long-range and economically sound policy for replacement of obsolete equipment and methods with special consideration to after-tax life cycle costs.

These principles are based on the accumulated experience of many experts in the field of materials handling and were compiled by the College-Industry Council on Materials-Handling Education (*8*). As with any such listing, they should be viewed as general principles for locating a starting point in developing a solution.

The elements of a materials-handling solution include personnel, equipment, facilities, capital, and time. The following questions should be answered during the formulation of a solution:

1. What personnel will be involved?
2. What training will be required?
3. What type of supervision will be needed?
4. How will production be affected (both positively and negatively)?
5. How will maintenance be affected?
6. What equipment will be needed?
7. What new facilities will be needed?
8. What will be the cost?

Usually the primary technical factors to be considered when answering these questions are (1) a knowledge of the types of handling equipment available, (2) their advantages and disadvantages, (3) their purchase, installation, and operating costs, and (4) their general utility in the mine.

Questions concerning reliability, maintenance, compatibility, and other technical issues should be asked about any proposed solutions. If possible, simulation models or other quantitative techniques should be used to evaluate the alternatives. The various proposed solutions should also be tested against economic criteria, and all direct and indirect costs should be taken into account.

After the technical and economic factors have been investigated, the intangibles must be considered. These items can make or break a solution and typically include the following:

1. Potential increases in safety.
2. Potential increases in morale.
3. Job enrichment.
4. Compatibility with established mining policy.
5. Operating feasibility.
6. Adaptability to future changes in the mining method.
7. Adaptability for expansion (or reduction).

Once a preferred solution has been identified, an implementation plan must be developed. Depending on the complexity of the proposed system, assistance may be required from equipment manufacturers, distributors, and systems contractors. After the system has been operating for a number of months, its performance should be audited to ensure it is justifying the investment. Additional engineering work and installation modifications may be necessary to fine-tune the operation.

SUMMARY

This chapter has presented the two most preferred strategies for reducing materials-handling injuries in underground coal mines: eliminating hazardous materials-handling tasks where possible and developing materials-handling hardware to meet specific materials-handling needs. After the redesigned tasks have been in operation for a few months, the changes should be reevaluated to ensure that all is proceeding as expected. Feedback should be solicited from the workers involved with implementing any changes in the supply-handling system, and additional engineering work and modifications may be necessary to fine-tune the operation.

Based on contacts made during the course of this research, there appears to be a sincere interest on the part on mine management and safety and production personnel in reducing materials-handling-related injuries. There is also the need for increased exposure to the types of materials-handling concepts presented in this chapter to stimulate further advances in addressing mine-specific materials-handling problems. Redesign of materials-handling activities through elimination of materials-handling tasks and the use of mechanical-assist devices represents the best method for reducing the cost and incidence of manual lifting injuries.

CHAPTER 3.–MATCHING JOB DEMANDS TO WORKER CAPABILITIES

Although redesign of the supply-handling system through task elimination and use of mechanical-assist devices represents the best opportunity to reduce musculoskeletal injuries, there will be some jobs where such changes are not possible. Ultimately, miners have to lift heavy materials to perform necessary underground mining tasks. However, there are methods that can reduce the risk of back injury, even when manual lifting must take place. As indicated in figure 1, the key to redesigning manual lifting tasks is to match the demands of the job to the physical capability of the worker to perform that job. For instance, the posture adopted by an underground miner to perform a lifting task can have a very considerable effect on how much weight is safe to lift. Therefore, if workers have to lift in certain postures, the risk of injury may be reduced by packaging materials in weights that do not exceed the amount considered safe to lift in those postures. Furthermore, certain lifting positions may cause workers to fatigue more quickly than others. In this case, the risk of injury can be reduced by providing

adequate rest so that muscular fatigue does not become the cause of a lost-time injury.

This chapter discusses redesign of manual lifting tasks according to the physical capabilities of underground miners as another useful method of reducing the incidence and cost of back injuries in low-seam coal mines. To better understand the stresses experienced by the low back during lifting tasks, a brief section describing the anatomy of the back and the causes of low-back pain is provided followed by a discussion of methods used by researchers to recommend acceptable lifting limits. The results of Bureau studies are then provided, which describe ways in which the lifting capacity of miners is affected by working in stooped and kneeling postures. The implications of these studies in terms of redesign of manual lifting tasks to reduce the worker's risk of injury are discussed.

ANATOMY OF THE BACK AND CAUSES OF LOW-BACK PAIN

When a worker lifts manually, the body (especially the low back) is subjected to significant physical strain. This is the reason that the number of manual lifting tasks should be reduced to the absolute minimum necessary. To better understand the load placed on the body when lifting and to identify the reasons workers experience back injuries, a basic understanding of the anatomy of the back is necessary.

The spine comprises 33 or 34 bones called vertebrae. These vertebrae are divided into five specific regions according to structure and function (fig. 15). The neck or cervical region comprises seven bones primarily designed to support the head. The midback or thoracic section of the spine contains 12 bones that get progressively larger down the spine. The thoracic vertebrae are the bones to which the ribs are attached. The low back or lumbar region of the spine contains five of the largest bones of the vertebral column, upon which the majority of the weight bearing of the trunk and head occurs. This is the region of the spine where the greatest strain is experienced when lifting, and it is not surprising that this is the region where the majority of back injuries occur. The lower two sections of the spine (the sacrum and coccyx) are made up of smaller, fused vertebrae.

The bones of the cervical, thoracic, and lumbar sections of the vertebral column are separated by oval, shock-absorbing intervertebral (IV) disks. The IV disk has two distinct sections (fig. 16). The outer portion of the disk is composed of tough ligamentous fibers that are arranged in a crisscross fashion, much like the plies on a radial-belted tire (*9*). The inner portion of the IV disk is made of a soft substance with the consistency of jelly. This part of the disk is what gives the disk its cushiony character. Experts believe that many back injuries are caused when the strong muscles of the back contract so vigorously that these disks are compressed so that the nerves exiting the spine at the lumbar region become "pinched," causing the muscles of the region to spasm, thus producing low-back pain.

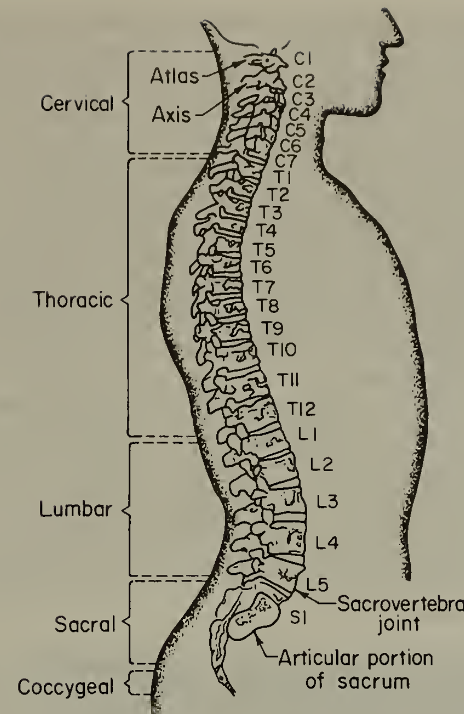

Figure 15.–Vertebral column. (Courtesy W. B. Saunders Co.)

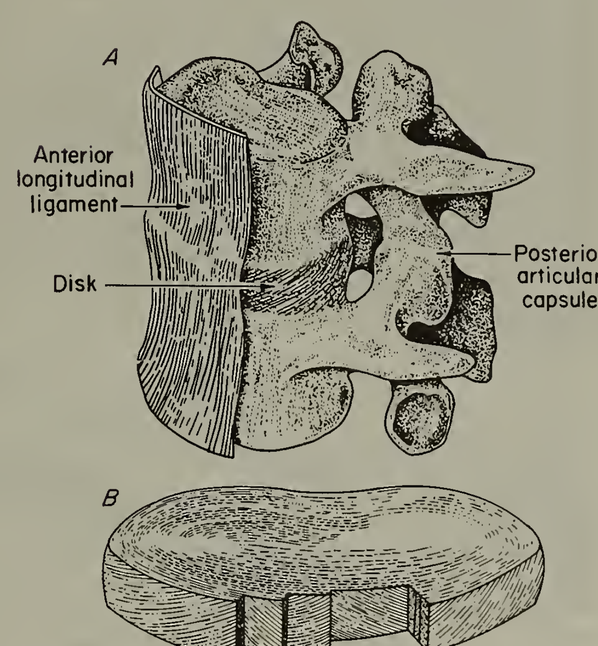

Figure 16.–Intervertebral disk. *A*, Separating two vertebral bones; *B*, Isolated view. Note the alternating layers of fibers permitting limited movement in all directions. (From "Oh, My Aching Back," by L. Root and T. Kiernan, 1975; reprinted by permission of David McKay Co., a division of Random House, Inc.)

The vertebral column has many muscles associated with it; these allow controlled movements of the trunk and provide additional support to the spine. During lifting tasks, the muscles of the back may generate more than 1,500 lb of force to perform the lift. Obviously, the contractile forces exerted by these muscles put a large amount of compressive strain on the vertebral column. The key to redesigning lifting tasks is to reduce the amount of force required of these muscles to moderate levels to reduce the compressive loading on the lumbar spine. Not only does this decrease the compressive load, it also decreases the probability of back muscle strain–another common cause of low-back pain.

Finally, the spine also has numerous ligaments associated with it. These ligaments are tough, fibrous bands of tissue that help to support the vertebral column. Ligaments are flexible, but only to a limited degree. Therefore, ligaments can be stretched only a small amount before they tear or rupture. If this occurs, instability and abnormal motion may occur, which may also lead to low-back pain.

METHODS OF DETERMINING LIFTING CAPACITY

There are three primary techniques used when researchers attempt to determine an acceptable weight of lift for a given task. These techniques are the biomechanical approach, the physiological approach, and the psychophysical approach. The biomechanical approach attempts to calculate the stresses experienced by the low back during materials-handling tasks and is generally useful for evaluating low-frequency lifting activities (*10*). The physiological approach uses measurements such as heart rate, oxygen consumption, and ventilation volume to establish an acceptable work load when lifting (*10-11*). The psychophysical approach allows test subjects to adjust the amount of weight contained in a lifting box to the amount they feel can be handled without undue stress or fatigue under specified conditions (*12*). Each of these methods has advantages and limitations, which are discussed in the following sections.

Biomechanical Approach

During manual lifting tasks, the lumbar region (low-back region) of the spinal column is subjected to much greater loads than any other area of the spine, and it is the region where most back injuries occur. The biomechanical approach to establishing lifting limits attempts to calculate the compressive load and shear forces imposed on the lumbar disks during materials-handling activities (*11*). The reason for the high forces produced on the lower back during lifting activities is the vigorous contraction of back muscles to counteract the mass of the weight being lifted (*13*).

An example of the biomechanical stresses experienced by the low back during a lifting task is shown in figure 17. As indicated in this figure, just holding a 50-lb box 1.75 ft in front of the spine requires the muscles of the low back to exert 700 lb of force. These muscles need to produce such a large amount of force because they are positioned so close to the spine (1-1/2 in away), yet they are having to counterbalance a weight that is 21 in from the spinal column (fig. 17*A*). However, if one brings the weight closer to the body, so that it is only 1 ft in front of the spine (fig. 17*B*), only 400 lb of force is required of the back muscles. Reducing the force exerted by the back muscles has the effect of diminishing the load experienced by the spine and thus decreases the risk of back injury. This biomechanical principle is the reason that workers are always instructed to "keep the load close" when lifting. From this example, it can be seen that calculating the biomechanical strains of lifting can help to redesign tasks so the stress on the low back is decreased. The biomechanical analysis technique can be extremely useful in determining the strain experienced by the low back in manual lifting tasks.

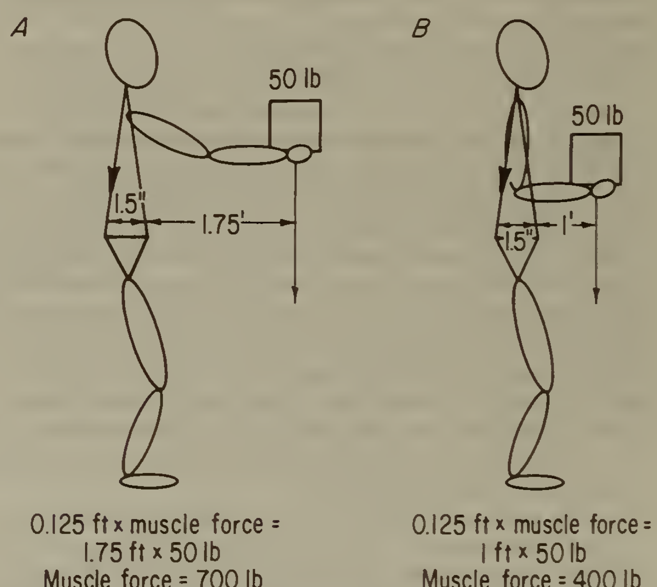

Figure 17.–Example of biomechanical stresses. *A*, **Holding an object at a far distance from the spine requires a tremendous amount of force to be developed by the back muscles;** *B*, **the amount of force can be reduced by holding the object closer to the body.**

Physiological Approach

This approach to establishing acceptable weights of lift relies on physiological measurements such as heart rate, oxygen consumption, or ventilatory volume to determine the amount of work a person can perform without undue fatigue (*10*). The physiological cost of muscular work can be easily determined by measuring the oxygen that is used during physical work (*14-15*) (fig. 18). When muscles become active, their increased metabolic demand spurs an increase in oxygen delivery by the heart and lungs. This is the reason for the higher heart rate and rate of breathing experienced during exercise or heavy work. This means that the difficulty of work being performed by an individual can be established. It is also well known that the harder an individual is working, the more quickly the muscles become fatigued. When muscular fatigue occurs, the worker may be more prone to injury (*14*).

Several factors are known to affect the physiological responses to lifting weight. These can be divided between worker variables and task variables (*4*). Among the major worker variables are gender, body weight, and the lifting method or technique used. The task variables may include the weight of the load, the frequency of lifting, the vertical distance the load is moved, and the temperature and humidity of the workplace. The NIOSH work practices guide (*4*) recommends that for occasional lifting (for 1 h or less), the metabolic energy expenditure rate should not exceed 9 kcal/min for physically fit males or 6.5 kcal/min for physically fit females. These metabolic expenditure rates correspond to oxygen consumption rates of 1.8 and 1.3 L/min, respectively. Heart rates for these tasks should not exceed 140 beats per minute for males or 120 beats per minute for females. Likewise, continuous (8-h) limits should not exceed 5.0 kcal/min for healthy males or 3.5 kcal/min for healthy females. The corresponding oxygen consumption rates are 1.0 and 0.7 L/min, respectively. Heart rates for these longer duration tasks are 110 beats per minute for males and 100 beats per minute for females (*4*).

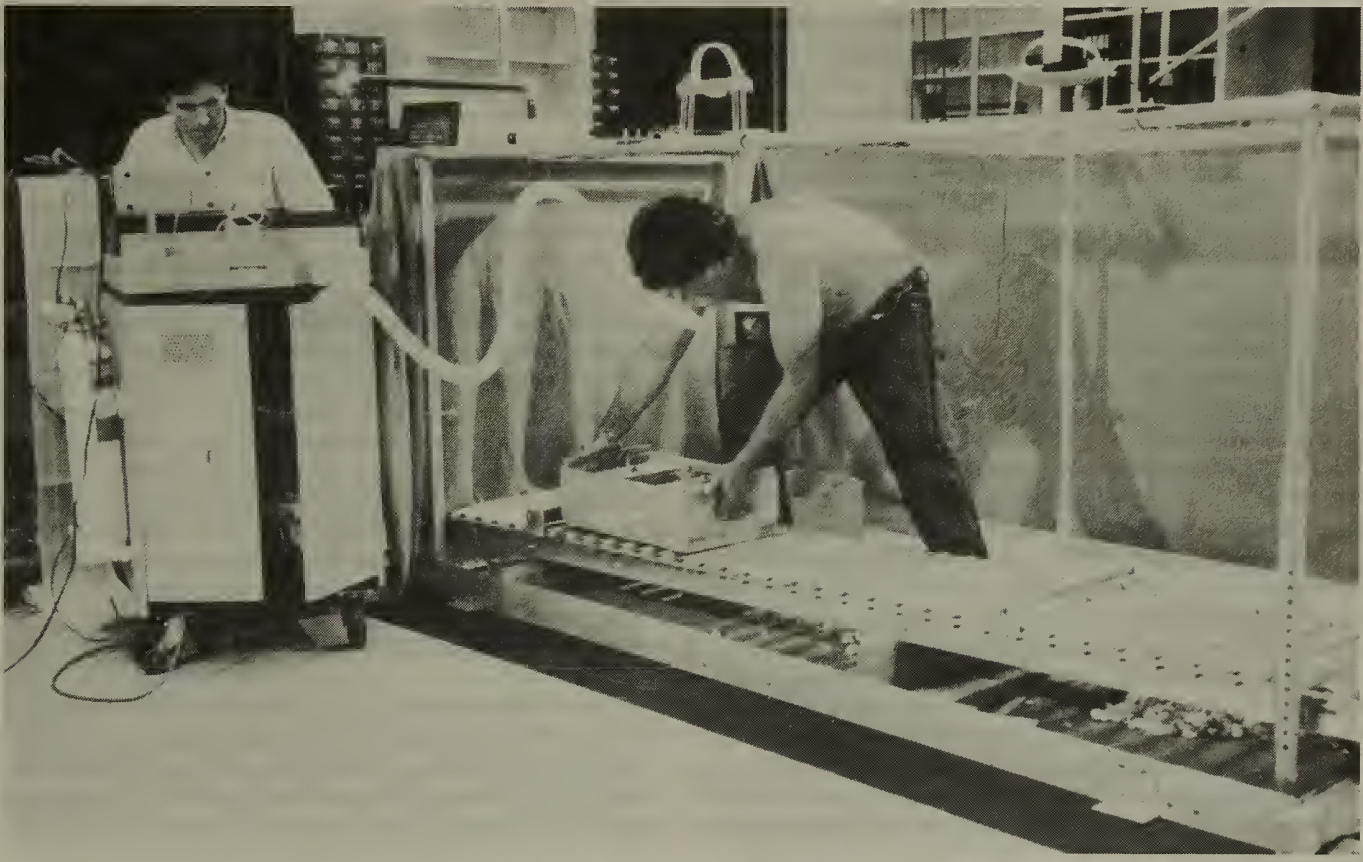

Figure 18.–Analyzing subject's expired air.

Psychophysical Approach

The third major method utilized in assessing lifting capacity is the psychophysical approach. The psychophysical approach assumes that the biomechanical and physiological stresses experienced by an individual during a lifting task are combined into a single measure of perceived stress (*10, 12*). The use of psychophysics in tests of lifting capacity generally allows the subject to be in control of the weight of the container being lifted. The subject is asked to adjust the weight of the box so that the lifting task does not lead to undue fatigue or overexertion (*16-17*). When this approach is used, two periods of lifting are common, one starting with a light box and one starting with a heavy box (*18*). The average weight chosen at the end of these two lifting periods is taken as the maximum acceptable weight of lift (MAWL) for the given task conditions (the frequency of lift, container size, posture, etc.).

The psychophysical method of determining permissible loads has many advantages. Psychophysics allows the realistic simulation of industrial work; for example, the lifting task can be a dynamic lift through a given distance. The frequency of lift may be varied to include either fast or slow rates, and intermittent tasks commonly found in industry can be examined. In addition, psychophysical results are very reproducible and appear to be related to low-back pain (*19*). The main disadvantage of the method is the fact that it is subjective, and it will probably be replaced when objective methods (such as biomechanical modeling) become more reliable.

Comparison of the Approaches

It has been suggested that the psychophysical approach may be the best single measure when determining acceptable weight-lifting burdens (*10*). The problem with using either the physiological or biomechanical approach alone to evaluate lifting capacity is that almost all lifting tasks have both biomechanical and physiological stresses associated with them. Furthermore, it is often the case that a particular lifting task may be within recommended limits for one of these methods, while exceeding the limits for the other. For example, lifting a very heavy weight one time does not require a very high expenditure of energy (and thus would be acceptable using physiological standards), but the biomechanical stresses associated with such a task might well exceed recommended limits. Conversely, lifting a lighter weight repetitively may be acceptable in terms of biomechanical stress, but the metabolic cost of the repetitive task would be greater and may exceed safe physiological limits.

In general, manual materials-handling recommendations based upon the biomechanical method tend to suggest lifting lighter loads more frequently. On the other hand, physiological models tend to advise lifting heavier loads less frequently (*10*). The preceding examples demonstrate that lifting is a complex task whose stresses cannot be fully explained by either the biomechanical or physiological approach alone. The virtue of the psychophysical approach is that it attempts to integrate the biomechanical and physiological stresses of a lifting task into a single measure of perceived stress.

BUREAU OF MINES LIFTING CAPACITY STUDIES

While a great deal of research has examined the lifting capacity of workers in unrestricted lifting postures, very little is known about the lifting capacity of underground miners in the restricted postures they must assume in low-seam coal mines. Therefore, the Bureau examined the lifting capacity of underground miners in stooped and kneeling postures. The results of these studies demonstrate how changes in posture can dramatically affect a miner's lifting capacity. Only the general findings of these studies are presented in this chapter; however, more detail can be found elsewhere (*20-22*).

The Bureau examined the lifting capacity of 25 underground miners (all members of the United Mine Workers of America) in both stooped and kneeling positions in two separate studies. The lifting task was asymmetric and was designed to simulate the unloading of a supply car in a low-seam mine (fig. 19). Both studies examined lifting capacity using the psychophysical method. As described previously, this method allows the miners to adjust the amount of weight in a lifting box according to their subjective estimate of lifting capacity in each posture–stooped or kneeling. There were two lifting periods in each posture: one starting with a light box (approximately 25 lb), the other starting with a heavy box (approximately 95 lb). The subjects were instructed to adjust the amount of weight in the lifting box by putting in or taking out steel weights until they reached the amount of weight they could handle without undue stress or fatigue. Periods of lifting were 20 min in duration, and the frequency of lifting was 10 per minute, a lifting frequency that the Bureau found to be about the average for compact, repetitively handled loads (*23*). The maximum acceptable weight of lift was taken as the average of the weight of the boxes from two lifting periods in each posture. The miners were not aware of the amount of weight they were lifting.

Lifting Capacity of Underground Miners

These studies demonstrated that miners have a significantly lower lifting capacity in the kneeling posture than in the stooped posture. In fact, the average miner lifted about 10 lb less in the kneeling posture than when stooped. The data in these two studies were used to establish recommended lifting limits for repetitively handled materials in underground coal mines. Such materials may include items such as rock dust bags, ventilation stopping blocks, crib blocks, roof bolts, cans of hydraulic oil, and other compact, frequently lifted supply items. The recommended maximum weights of lift for repetitively handled items in the stooped posture is 55 lb, while the recommended maximum weight of lift for these items in the kneeling posture is only 45 lb. The miners used in these

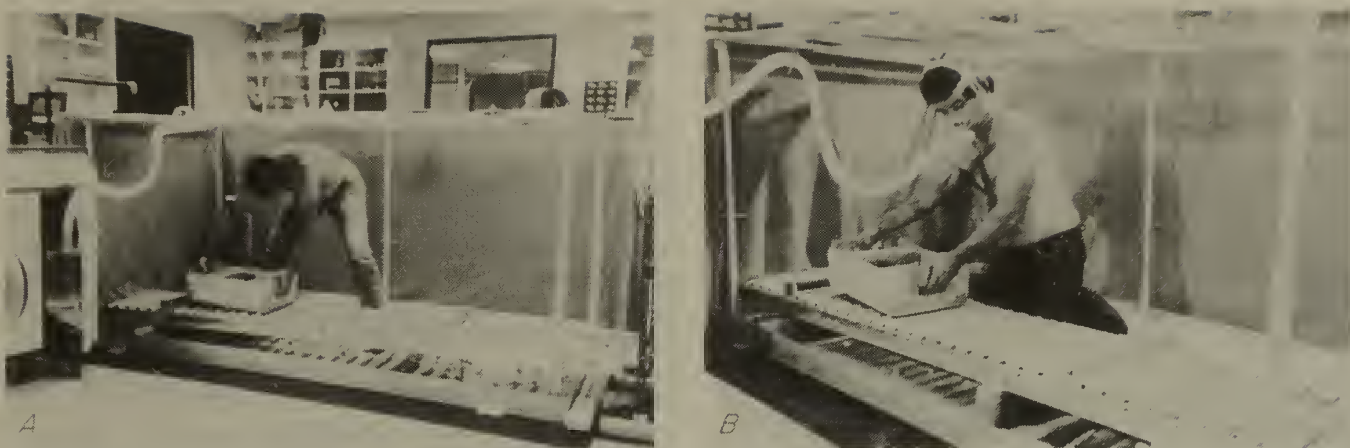

Figure 19.–Underground miners performing lifting capacity tests at Bureau of Mines Ergonomics Laboratory.

lifting studies were probably in better physical condition than other miners, owing to the thorough medical screening performed. This medical screening included a thorough physical examination and graded exercise tolerance test (*21*). Furthermore, any candidates with prior history of lost-time back injury were excluded from participation. Therefore, the recommended weights described here may exceed the amount that less healthy miners can safely lift.

The results of the Bureau's lifting capacity tests have useful implications for proper design of materials that must be lifted in low-seam coal mines. Perhaps the most commonly handled material in underground coal mines is a 50-lb rock dust bag. While the 50-lb weight is less than the recommended limit for the stooped posture, it exceeds the recommended weight for the kneeling posture. Results of the Bureau's studies indicate that compact, repetitively handled supplies in low-seam mines should be packaged in containers weighing less than 45 lb (the recommended limit for lifting in the kneeling posture), because of the decreased lifting capacity of miners in the kneeling posture.

It should be noted that these recommended limits apply only to repetitively handled materials such as those listed above. When materials are lifted at a lower frequency, it would be expected that somewhat greater weight could be lifted. However, a recent Bureau study has shown that lifting capacity is significantly lower in the kneeling posture than stooped, even with lower frequency materials-handling tasks.

Physiological Stress of Lifting in Restricted Postures

Results of the physiological measurements taken during the lifting capacity tests indicated that, despite the fact that miners lifted less weight in the kneeling posture, the physiological cost of lifting in this posture was actually greater than that experienced when stooped. Heart rate, oxygen consumption, and ventilation volume were all found to be significantly higher in the kneeling position. This indicates that workers may fatigue more quickly when lifting in the kneeling posture. While lifting tasks in underground mines are generally sporadic enough to allow sufficient rest, more frequent rest breaks should be allowed when miners must handle materials for prolonged periods in the kneeling posture to reduce the risk of injury due to fatigue.

Biomechanics of Lifting in Restricted Postures

Analysis of data collected relating to muscular activity of trunk muscles (electromyography) during the lifting tasks indicated that the large muscles of the lower back contracted much more vigorously in the kneeling posture than in the stooped posture. This implies a greater compressive loading on the spine while kneeling, hence a greater chance of back injury. Apparently, the back muscles take on added responsibility for lifting when kneeling, because of the reduced muscle mass available to perform the work. In the stooped posture, the worker has more use of the leg muscles to help with the lift and can therefore execute a whole-body exertion. This may be one reason why the lifting capacity is higher in the stooped posture.

Results of an experiment investigating the effect of posture on back strength indicate that back strength is decreased by about 10 to 15 pct when kneeling (*20*). This fact may help to explain the lower lifting capacity demonstrated in the kneeling position. The diminished force-producing capability of the back muscles in this posture may also help to explain the fact that these muscles demonstrate greatly increased activity when a person is lifting in the kneeling posture. It would seem reasonable to assume that these muscles would have to work harder to perform a lift when a person is kneeling if their overall strength capability in this position is decreased.

Both postures commonly used for manual lifting in underground mines present serious problems for the worker, and neither posture should be used for lifting unless it is unavoidable. The lifting studies showed that kneeling is a very stressful posture in which to lift. The lifting capacity of underground miners is significantly lower in the kneeling posture than when stooped. This is due to the reduced amount of muscle that can be used to perform the lift when kneeling. In addition, the physiological cost of lifting is higher when kneeling–workers are likely to fatigue more quickly when lifting in this posture. The low-back muscles contract much more vigorously in the kneeling posture, indicating that the compression on the disks of the spine may be increased in this posture. This increase in muscular activity also indicates that the chances of muscular strain may be increased when lifting in the kneeling posture.

While the stooped posture appears to have some advantages over the kneeling position (that is, increased lifting capacity, lower metabolic cost, and less back muscle activity), the stooped posture is also very hazardous (*13, 24-27*). This posture can put a large amount of loading on the ligaments of the low back, which contain many pain-sensitive nerve endings; many researchers feel that stressing these ligaments leads to low-back pain (*27*). This indicates that the chances of a ligament sprain may be increased in the stooped posture. In addition to the ligament stress experienced in the stooped posture, the spine is in a very flexed position, which causes a great deal of pressure on the rear portion of the disks of the lumbar spine. Many researchers agree that this may cause low-back pain by caus-ing the back of the disk to deform in the area where many pain-sensitive nerves are present (*13, 24-27*).

Given the previous information, how can the chances be reduced that a worker will experience a low-back injury in these two stressful postures? It is important to reduce the amount of weight of supplies that are handled in the kneeling posture (because of the reduced lifting capacity observed while kneeling). This reduces the chances that the miner will overstrain back muscles when kneeling. In addition, reducing the weight of supplies decreases the likelihood that muscular fatigue will be the cause of a lost-time injury.

While Bureau research has demonstrated that miners have an increased lifting capacity in the stooped posture, lifting periods in this posture should not be prolonged, because of the strain placed on the intervertebral disks and the ligaments of the lumbar spine. When miners lift in a stooped posture, they should perform back extension exercises to reduce the strain on the disk and ligaments, and to restore the lordosis (forward curvature) of the lumbar spine. Chapter 5 describes an exercise called the prone pushup, which is an excellent exercise after working in a stooped posture. This exercise can be performed in almost any low-seam coal mine and, if performed correctly, may significantly improve the back status of underground coal miners.

REDESIGNING MANUAL LIFTING TASKS TO MINER'S PHYSICAL CAPABILITIES

The Bureau studies described above indicate that the posture used for an underground lifting task has a significant effect on the ability of the miner to accomplish the task. The job demands placed on the worker need to match the capabilities of the worker when performing materials-handling tasks in restricted postures. The results of the lifting studies can be used to recommend procedures that should be followed when lifting in the restricted postures that must be assumed in low-seam mines.

Maximum Recommended Weights of Lift

The results of the psychophysical tests of lifting capacity of underground coal miners have demonstrated that the lifting capacity of miners in the kneeling posture is significantly lower than that of miners in the stooped posture. An acceptable weight of lift is defined as one that 90 pct of the working population are able to lift using the psychophysical methodology (*28*). Using this criterion, the maximum recommended weights of lift for repetitively handled materials in low-seam coal mines are 55 lb in the stooped posture and 45 lb in the kneeling posture. Because miners are likely to use the kneeling posture for all commonly handled supplies at some time or another in low-seam mines, all compact, repetitively handled materials should be packaged in a weight not exceeding 45 lb.

Redesign of Materials

The results of the lifting capacity studies indicate that serious consideration should be given to redesigning repetitively handled materials to conform to the recommended weight of lift in the kneeling posture. For example, rock dust bags might be reduced in weight from the current 50-lb bag to a 40-lb bag. Similarly, other repetitively handled materials should be redesigned to match the demonstrated lifting capacity of underground miners in these postures.

It is clear that the materials delivered to low-seam mines by the supplier have been packaged in weights that have been shown to be acceptable when a worker is able to lift in a standing posture. However, the results of these Bureau studies indicate these weights are not appropriate when workers have to lift in the restricted postures characteristic of low-seam mines. The lifting posture has an important influence on the amount of weight that is safe to lift, so that workers are not subjected to a high risk of injury when they have to lift in awkward positions. An analysis of back injuries in coal mines has indicated that the rate of back injuries was higher in coal seams less than 48 in than in seams thicker than 48 in. This may be due to the fact that workers are being required to lift weights that actually exceed their lifting capacity in the kneeling posture. Redesigning the weight of repetitively handled

supplies according to the recommended limits described above may significantly reduce both the incidence and cost of back injuries in low-seam coal mines.

Handling Heavy Weights

Given a choice of handling a heavy weight (>50 lb) in the stooped or kneeling position, it may be better to handle the weight stooped, because of the higher lifting capacity demonstrated in this posture. Because more muscles can be called upon to lift in the stooped posture, this posture may be better, though admittedly not a great deal better, for handling compact, heavy loads (fig. 20). Since the spine is severely flexed in the stooped posture, a back extension exercise (such as the one presented in the back fitness program in chapter 5) should be performed after lifts in the stooped posture (*27*).

Figure 20.–Miners have higher lifting capacity when stooped.

Reducing Lifting Frequency

If the weight of the object cannot be reduced, it is possible to decrease the stress of the lifting task by having the worker reduce the number of times that the object is lifted per minute. This not only reduces the amount of stress experienced by the spine per minute, it also reduces the physiological cost of lifting, thus delaying the onset of muscular fatigue.

Need for More Frequent Rest Breaks When Kneeling

Metabolic demands may be increased when handling materials in the kneeling posture. In fact, the underground miners tested to date have demonstrated that both heart rate and ventilation volume have been significantly higher in the kneeling posture than stooped, despite the fact that significantly less weight was lifted when kneeling. Many studies have made it clear that activities with higher metabolic demands require more frequent rest intervals. Therefore, to prevent the onset of muscular fatigue that may ultimately lead to musculoskeletal injury, more frequent rest breaks may be necessary in the kneeling posture (fig. 21) when prolonged manual lifting is performed.

Figure 21.–Miners may fatigue more quickly when kneeling.

Stresses of Lifting When Stooped

Certain individuals were not as tolerant to long periods of working in the stooped posture, even though these individuals lifted more weight in this position. These subjects were generally those who had previous incidence of low-back pain. Overweight individuals also tended to be more sensitive to stooped materials handling. Therefore, it is suggested that individuals who have experienced serious low-back pain or who are overweight exercise particular caution when handling materials while stooped. Shorter periods of materials handling in this posture are indicated for such individuals to prevent reoccurrence of low-back pain (fig. 22).

Figure 22.–Stooped posture may be less tolerable for some miners.

In addition, activities involving prolonged stooping should be interrupted regularly by either standing upright (if possible) or performing the back extension stretch described in chapter 5 in the back fitness program. If possible, a lumbar lordosis should be maintained when lifting in the stooped posture.

Modification of Work Environment

If supplies have to be stored in an underground area, mine management should seriously consider cutting enough roof to create a storage area where the miners can stand upright when loading and unloading vehicles. Considering the compensation costs (and other related costs) associated with lost-time back injuries, it seems quite appropriate to look for any possible method to reduce the loading to a worker's lower back. If the roof is cut, the supplies can be stacked on pallets or other support materials that are at knee height, not ground level. Research (*29*) has shown that a worker is three times more likely to experience a back injury when lifting from the ground than from knee height. Thus, cutting roof so that workers can stand upright would reduce the severe biomechanical strain placed on the workers' backs when they bend over to pick up items from the floor. The costs involved with cutting the rock from the roof and properly supporting the area can be far less than the direct and indirect costs of a lost-time back injury.

Lifting Technique

While the amount of weight that is safe to lift in restricted postures is lower than that which is acceptable in unrestricted postures, many of the traditional principles of safe lifting are applicable to underground manual materials handling. The following section summarizes many of the important factors that apply to performing manual lifting tasks in low-seam mines, no matter which posture is adopted.

Use a Smooth Lifting Motion

Research has indicated that sudden or unexpected movements are responsible for a large number of back injuries. The sudden load experienced by a worker's back in this situation is often two to three times as great as when the load is expected (*30*). Related to this concept is the recommendation that if an object is stuck underneath other materials, do not attempt to lift it without first removing the debris on top of it. Two problems can be caused by this situation. First, the object may not move when the worker expects it to; this causes a very high load to be experienced by the lower back. Second, the object may pull free unexpectedly, which also places the low back under extremely high stress.

Keep the Load Close to the Body

The principles of biomechanics (discussed earlier in chapter 3) indicate that the further the load is from the spine, the greater the stress to the low back. Therefore, it is important to keep the load close. While restricted postures may limit how close the load can be to the body, it is still much better to handle the material so that the load is as close to the body as is practicable.

Avoid Excessive Twisting

Many researchers are of the opinion that the worst action when lifting is twisting. Twisting puts a severe strain on the fibers of the intervertebral disk and may actually cause some of these fibers to break, which severely weakens the disk. Furthermore, it is the opinion of some researchers (*26*) that injuries to the disk caused by twisting are much less likely to heal than injuries to the disk due to simple bending. Therefore, it is important to position the body so that a minimum of twisting is required to perform a lifting task (fig. 23).

Get Help for Heavy Objects

Many back injuries occur when a person tries to lift more weight than one individual can safely lift. Waiting a little extra time for help may prevent back injuries that may plague workers for the rest of their lives (fig. 24).

Figure 23.–Twisting during a lift.

Figure 24.–Miners assisting one another with heavy load.

SUMMARY

While elimination of lifting tasks and use of mechanical-assist devices are the best methods of reducing materials-handling injuries, it is not always possible to redesign jobs using these methods. This chapter has presented another method that can be useful in reducing injuries experienced in low-coal mines–matching the lifting demands of a job to the worker's lifting capabilities. For instance, Bureau studies have indicated that the lifting capacity of miners is significantly lower in a kneeling posture than when stooped. In fact, the maximum recommended weight of lift for compact, repetitively handled materials (such as rock dust bags, stopping block, crib block, etc.) is 55 lb in the stooped posture, but only 45 lb in the kneeling posture. Furthermore, the physiological demands on the body are increased when kneeling, even though less weight may be lifted in this posture. This indicates that miners fatigue more quickly in the kneeling posture than when stooped. Reducing the weight of materials that must be manually handled in the restricted postures used in low-seam coal mines may significantly reduce back injuries due to over-exertion in underground lifting tasks.

CHAPTER 4.–EXAMPLES OF ALTERNATIVE REDESIGN STRATEGIES

This chapter provides examples of alternative strategies in the redesign of materials-handling tasks in low-seam coal mines. The examples follow the model for redesign of materials-handling tasks shown in figure 1. According to this model, once a materials-handling problem has been identified, the first step is to try to find a way that the job can be eliminated. If this solution is not feasible, the next step is to use or develop a mechanical-assist device to perform the job in order to eliminate the need to manually lift materials. If neither of these options is possible, an attempt should be made to modify the lifting task so that it does not exceed the lifting capacity of underground miners working in restricted postures. While it is usually possible to use one of these three methods, occasionally no physical redesign of the job or workplace is possible. In such cases, worker selection and training procedures are needed. Some of the following examples are based upon successful redesign strategies already implemented by some low-seam coal mines, which have not only reduced the risk of injury to the workers but have also increased the productivity of the crew. This chapter also discusses implementation and evaluation of redesign strategies.

ELIMINATION OF MATERIALS-HANDLING TASKS

A task analysis at a low-seam coal mine has determined that many supplies are handled excessively once the supply car reaches the underground storage section (*31*). As an example, when the supply car arrives at the storage point, 400 heavy items (for example, rock dust bags, concrete block, etc.) are unloaded from the car onto supply piles, after which the supply car returns to the surface for another load. Eventually the stacked supplies are handled again to be transported to the production section for their end use. Therefore, a total of 800 manual lifts are required in the storage section alone.

One mine has found that the number of lifts can be dramatically reduced by keeping the supplies stored on the supply car in the storage area. This strategy immediately eliminates 400 of the manual lifts required in the storage section (unloading the supply car and stacking materials onto piles), each one of which may be a potential cause of a lost-time injury. The supplies now need to be manually handled only once–from the supply car to the scoop for transportation to the area of end use. In addition, the mine has found that this strategy can help keep supplies palletized and lifted through mechanical means almost exclusively. In fact, some supplies at this mine are handled manually only once–during the end use of the item. All other times, the supplies are handled as unit loads by forklift or by scoop. Obviously, this strategy may require the purchase of additional equipment (supply cars) that can be stored underground. However, when the costs of not using this strategy (for example, costs of lost-time injuries, decreased productivity of the crew, etc.) are totaled, any purchase that can decrease the risk of back injuries can indeed be a cost-effective and wise investment. In fact, prevention of just one lost-time back injury may pay for the investment in the extra equipment. Eliminating materials-handling tasks is the best method for controlling the costs associated with back injuries in underground coal mines.

REDESIGNING MATERIALS-HANDLING TASKS USING MECHANICAL-ASSIST DEVICES

An accident analysis by an eastern coal mine demonstrated that all members of a four-person crew had experienced lost-time injuries due to lifting heavy rail (approximately 550 lb) for roof support. Obviously, this is not a materials-handling task that can be eliminated– the roof needed to be supported by sections of rail. If a materials-handling chore cannot be eliminated, the next best strategy is to utilize or develop a mechanical-assist device to accomplish the task. Such a device was discussed in chapter 2 of this report, the beam-raising vehicle. This device uses a modified automotive floor jack to raise beams for roof support. The beam-raising vehicle effectively eliminates the need to manually lift these beams, thus avoiding the risk of injury due to an extremely heavy lifting task. Since this device has been put into service, the crew has not experienced any lost-time injuries due to performance of this job and has also become significantly more productive. It should be emphasized that the design of this device is simple enough that most mine shops could fabricate this piece of equipment on their own. The plans for this mechanical-assist device (and others described in chapter 2) are available from the Bureau (*7*).

REDESIGNING LIFTING TASKS TO FIT WORKER LIFTING CAPACITY

A task analysis at a small low-seam coal mine has indicated that the most commonly handled supply items at the mine are rock dust bags, which weigh 50 lb. While this mine has eliminated and mechanized several of the steps in the transfer of rock dust, there are still significant periods of repetitive manual lifting of these bags needed underground in severely restricted lifting postures. In many low areas of the mine, the only posture that can be used to lift these bags is the kneeling posture. However, the 50-lb weight of these bags exceeds the recommended weight of lift for repetitively handled materials in the kneeling posture, according to the lifting capacity studies by the Bureau. Materials that are repetitively handled in the kneeling posture should not exceed 45 lb. Since the lifting tasks cannot be eliminated or mechanized by this mine, the weight of the rock dust bags needs to be reduced to conform to the reduced lifting capacity of miners in the kneeling posture. Therefore, the supplier of rock dust should be contacted and instructed to supply the rock dust in 40-lb bags, instead of the current 50-lb containers, so that the load does not exceed the recommended weight of lift for the kneeling posture. Other repetitively handled materials should also be redesigned to conform to the lifting capacity of underground miners in restricted postures. Redesigning materials in this way has been shown to be an effective method of reducing the costs and incidence of back injuries (*28*).

WORKER SELECTION AND TRAINING PROCEDURES

Worker Selection

While most jobs can be redesigned through one of the three approaches described above, occasionally such redesign may not be possible. Consider the following example. A low-seam mine requires the building of permanent ventilation stoppings using solid concrete block, weighing about 65 lb. Obviously, the need to build these stoppings means that the job cannot be eliminated. Because of the complex nature of the lifting task, no suitable means of mechanizing this task is currently available. The mine has contacted the supplier and requested that the solid concrete block be reduced in weight to 45 lb (the acceptable weight limit for repetitively handled materials in the kneeling posture), but the supplier will not be able to supply the lighter blocks in the near future. In this example, the three preferred methods of redesigning the task cannot be used. In this case, it may be useful to select the worker who may be more apt to withstand the stresses of the job and who would therefore be at a lower risk of injury.

Any test used to determine a worker's suitability for a job must be related to the specific demands of the job. (A task analysis can be used to ascertain the demands of a job.) If the test does not meet this criterion, then the selection procedure may be viewed as discriminatory, and legal action may result (*32-33*). In addition to relating to the specific demands of the job, the test should be safe, should produce reliable results, should be practical to administer, and should be able to provide a reasonable prediction of future injury or illness (*32-33*).

Since strength is an important factor in the ability to perform manual lifting tasks, a static strength test would be a reasonable test on which to base a decision as to which workers would be at less risk of injury in constructing the permanent ventilation stopping. Therefore, the mine arranged to have tests done of the lifting strength of five of its laborers in a kneeling posture. Test results showed that Frank's lifting strength was 170 lb, Bob's was 162 lb, Bill's was 150 lb, Ray's strength was 139 lb, and Mike's was 125 lb. The results indicate that Frank may be the best candidate for the job (less likely to become injured while building the solid-block ventilation stopping), because of his greater strength capability. If three workers are required for the task, Frank, Bob, Bill would be the recommended selections. The other workers should be assigned to chores that have been mechanized or designed not to exceed the recommended weight limits for repetitively handled materials (as described in the previous chapter). Proper worker selection procedures can be a useful tool in controlling the costs of back injuries in low-seam coal mines. A further discussion of worker selection and training criteria can be found in reference 33.

Worker Training

While efforts to educate and train workers are an important part of the overall safety strategy to reduce back injuries, this approach appears to be much less effective in reducing these injuries than the redesign approaches detailed previously. However, a thoughtfully designed training program can provide useful information and knowledge to the worker that can help minimize the risk of injury that may otherwise occur because of ignorance of certain fundamental concepts of manual lifting. The contents of such a course should include a basic understanding of the anatomy of the back, biomechanics of lifting, proper posture at work and at home, and physical fitness for back protection at work and at home, as well as simple concepts on psychological factors that may predispose a worker to injury (anxiety or stress on the job or at home, motivation, interactions on the job, etc.). The course should also provide hands-on experience in proper lifting techniques (*32, 34*).

In addition to the general training course contents described above, it may be useful to inform the workers of the results of the Bureau's lifting studies. For instance, miners should be made aware of the fact that lifting capacity is significantly reduced in the kneeling posture as opposed to the stooped position. This means that if the worker has to lift a heavy object (≥45 lbs), it may be better to handle the object in the stooped posture because of the increased lifting capacity in this posture. In addition, the Bureau studies have indicated that muscular fatigue occurs more quickly in the kneeling posture; thus, more frequent rest breaks should be taken in this posture. Providing specific information about the stresses of lifting in the restricted postures that low-seam miners have to use may help to reduce manual lifting injuries by increasing the worker's understanding of the limitations of lifting in these postures.

IMPLEMENTATION AND EVALUATION OF REDESIGN STRATEGY

Once a choice for the redesign of the task has been made, the new strategy must be put into effect. This step in the process often requires active communication among a number of individuals not influenced by the process until this point. Many of these individuals may play a very important role in whether the implementation of the strategy is successful (*35*). Though management might initiate a new method of performing a particular task, unless the idea is supported by the miners who must carry out the plan, implementation will be difficult.

Evaluation of the newly implemented materials-handling strategy is another crucial step in the process of redesigning the system. Occasionally, the strategy used to redesign a task may overlook important, unintended consequences. Therefore, it is crucial to get feedback on how the changes are working and how well the miners are accepting the new procedures (as well as soliciting suggestions from them on how the new plan might be made more effective). Unintended consequences are not always negative. For instance, a miner may find that a newly developed mechanical-assist device may work better for a lifting task other than the one for which it was originally developed. Nonetheless, providing the new mechanical-assist device will have been beneficial in reducing the number of times an object is manually lifted. Evaluation should consist of a systematized method of determining if the redesign strategy has fulfilled the desired goal of reducing the worker's risk of injury.

SUMMARY

This chapter has provided examples of several methods that can be used to redesign materials-handling tasks in low-seam coal mines to reduce the incidence and cost of musculoskeletal injuries. Many underground materials-handling tasks can be either eliminated or mechanized to reduce the number of manual lifts required in the supply-handling system. For tasks that cannot be eliminated or mechanized, the demands of the job can be matched to the worker's capabilities to perform the job. Occasionally, it may not be possible to use any of the three approaches mentioned above. In such cases, worker selection and training procedures may be the only methods that can be used to reduce the risk of worker injury. The examples in this chapter were provided to encourage mine management to evaluate current methods of handling supplies and to improve the supply system through the redesign strategies described.

CHAPTER 5.–MANAGEMENT POLICY AND CONTROL OF BACK INJURY COSTS

While the major focus of this report is that many jobs in low-seam coal mines can be ergonomically redesigned to reduce the risk of back injury, there are other ways that management can minimize the costs associated with these injuries. The first is to make a commitment to improving the physical fitness of the company's work force. The second deals with the way in which management responds when a back injury does occur.

PROMOTION OF PHYSICAL FITNESS

Mining can be a physically demanding job, which means that miners should be physically fit to meet the requirements of the job. Unfortunately, research has shown that miners may actually be a bit less fit than other industrial workers (*36*). This indicates the importance of proper physical conditioning so that miners can better cope with

the demands of the job. Management support for programs that help to keep the work force more physically fit may substantially reduce the costs associated with musculoskeletal injuries.

Back Fitness Program

Low-seam coal miners spend a large portion of the working day in a posture that flexes the spine severely. Therefore, passive extension exercises (see the prone pushup below) to relieve the pressure experienced by the lumbar disks when the spine is flexed are recommended periodically throughout the workday. In addition, this program includes exercises to strengthen the abdominal muscles and the back extensor muscle group. The back fitness plan described below is a simple, effective method of caring for the back without spending much time in the process. However, such a program must be followed conscientiously to gain the maximum benefit. <u>The worker should consult with a physician prior to participation in any exercise program!</u>

Step 1. Prone Pushup and Back Stretch

Miners who work in low coal spend a large amount of time with their spines flexed, which creates a great deal of stress on the intervertebral disks, especially of the lumbar (low back) region. When the vertebral column is flexed, the jellylike material in the disk is moved toward the back of the disk, creating stress on the rear portion of the disk. Continued pressure on this region causes fibers of the disk to weaken and perhaps tear, thus leading to a back injury. Given the extreme amount of time spent in the flexed posture by underground miners, it is crucial that they perform exercises that put the vertebral column in extension. Such exercises have the effect of relieving the pressure on the posterior (rear) portion of the disk and on the sensitive spinal nerve roots (*27*).

By far the best exercise to achieve the goals stated above is the prone pushup. This exercise takes only a few minutes a day and yet can have a dramatic effect on the status of the low-back region. In fact, this exercise is often effective as the first treatment when the low back is injured. In addition, this exercise (as well as the other exercises described below) can be performed in almost any low-seam coal mine.

For the prone pushup (see figure 25*A*), lie flat on the stomach and, with the hands directly beneath the shoulders, push up while keeping the pelvis flat against the ground. Each pushup should be performed to the point of feeling a stretching or mild discomfort in the low back. A series of 10 pushups should be executed, followed by back stretches. The back stretches are performed by lying on the back and raising the left knee to the chest, then switching legs and raising the right knee to the chest, and finally raising both knees to the chest (fig. 25*B*). These back stretches should be followed by another series of 10 prone pushups (fig. 25*C*). This procedure should be performed two to four times a day.

Step 2. Strengthening the Abdominal Muscle Group

Strong abdominal muscles are also important in keeping a back healthy. However, the traditional exercise recommended for strengthening the abdominals (situps) can actually be quite harmful to the back. A much better alternative is the half situp, shown in figure 26*A*. This exercise has the desired effect of increasing abdominal strength without loading the back to the extent that traditional situps do. This exercise should be performed 3 times a week with at least 20 half situps per session. The oblique abdominal muscles are best strengthened by the bicycle exercise shown in figure 26*B*. Each leg should execute at least 30 repetitions, and legs should be alternated during this exercise. This exercise should be performed three times per week; however, it should not be performed if low back pain is currently being experienced.

Step 3. Strengthening the Back Muscles

Strengthening the back muscles is also recommended for underground miners. Increasing the strength of the back extensor muscles gives them an added reserve to rely upon when performing stressful manual materials-handling activities in restricted postures. A simple, yet effective, exercise is shown in figure 27. In this exercise, lie flat on the stomach, interlock hands behind the head, and arch the back as far as possible for a count of 10. This exercise should be repeated five times during a session (one session per day). However, this exercise should not be performed if low-back pain is currently being experienced.

Adherence to the simple exercise program outlined above may significantly reduce the cost and incidence of back pain in the underground mining industry. This back program would take only a few minutes out of the workday, and management is encouraged to consider instituting such a program that would be performed by the miners during the workday.

Stretching

Probably the most important (and most neglected) action that can be taken to reduce the risk of overexertion injuries is to properly warm up before physically demanding tasks. Muscles that are "cold" (unstretched) are much more likely to be injured than those that have been properly prepared for activity through stretching. Stretching allows a muscle to receive more blood and oxygen and literally warms up the muscle. This allows the muscle to become more resistant to injury and actually increases the strength that can be produced by the muscle (*37-38*).

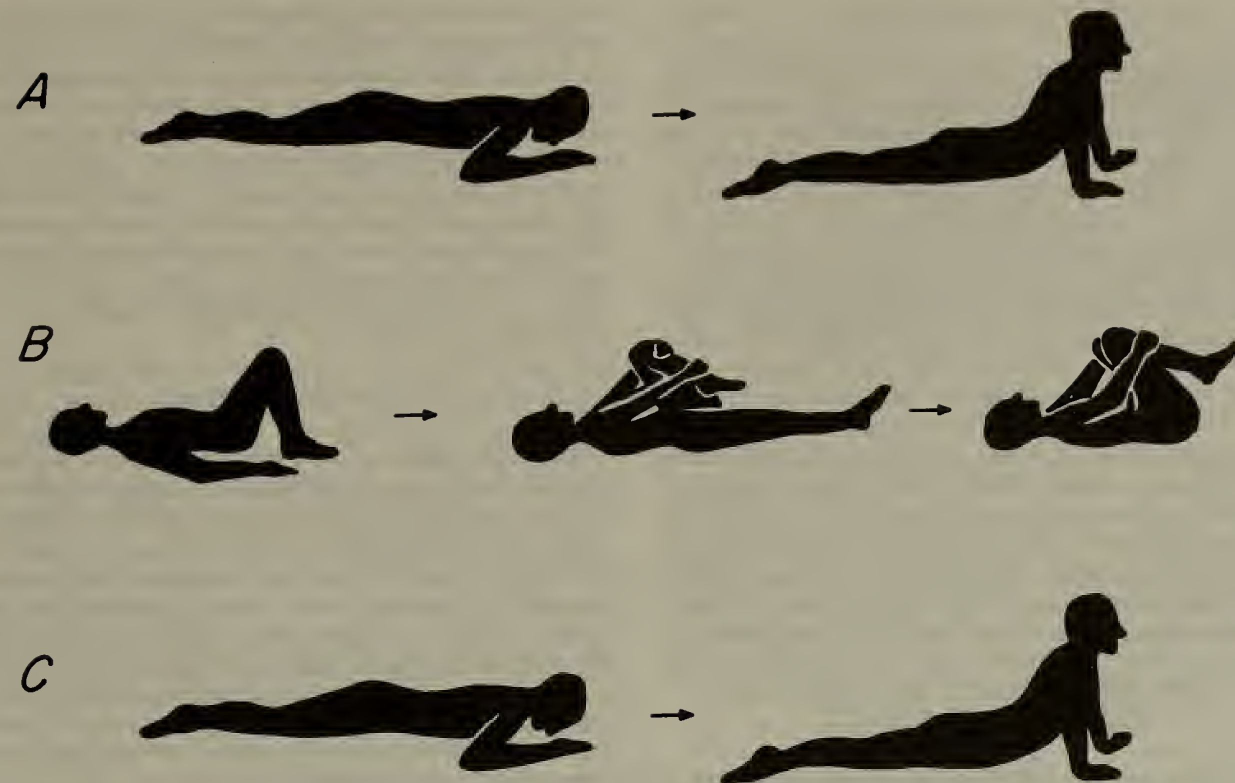

Figure 25.–Prone pushup and back stretch. *A*, Begin with 10 prone pushups; *B*, follow with 3 sets of knee-to-chest stretches; *C*, finish with 10 more prone pushups.

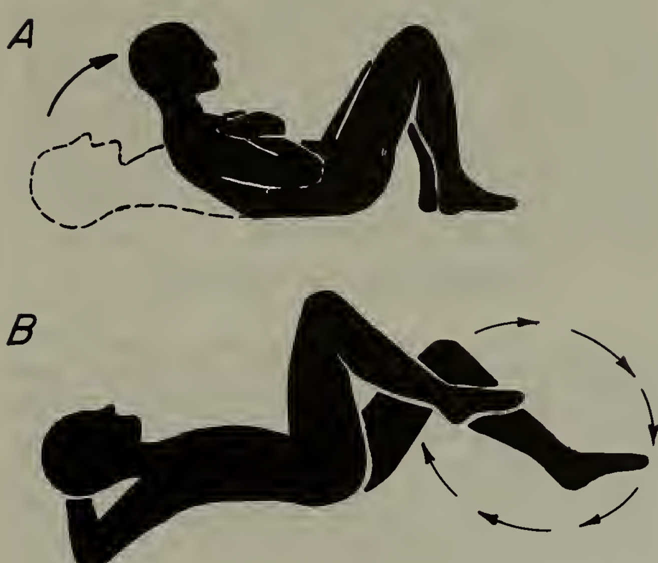

Figure 26.–Abdominal strengthening exercises; these should be performed three times weekly. *A*, Half situp; *B*, horizontal bicycle.

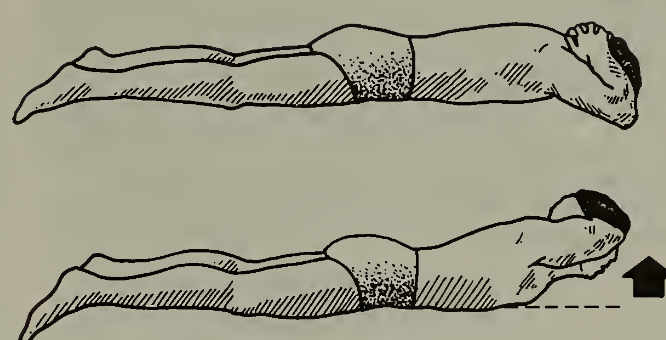

Figure 27.–Strengthening back muscles. (From "Oh, My Aching Back," by L. Root and T. Kiernan, 1975; reprinted by permission of David McKay Co., a division of Random House, Inc.)

Strength Conditioning

Strength conditioning, another method that can reduce the risk of injury, involves strengthening the muscles and joints through weight training. However, care should be taken to follow safe weight-training procedures, because improper weight training can be more hazardous than no training at all. Some mine operators have provided exercise and weight-lifting equipment for use by their miners. This is an excellent method of helping to keep the work force in better condition so that they are better able to cope with the stresses of working underground.

Back Care at Home

Management should also emphasize that back care should not stop at the minesite. Many back injuries may be caused by everyday activities such as driving with the car seat too far back, doing yard work, or sleeping on a mattress that is too soft. There are also two-person lifting tasks at home. The safe lifting techniques employed at work should be transferred to the home environment.

CONTROL OF COSTS ONCE A BACK INJURY HAS OCCURRED

The previous sections have detailed methods that can be useful in preventing low-back injuries. However, it is important for management to realize that some back injuries probably will occur, despite efforts to prevent them. When back injuries do occur, the policy that management puts in place to deal with the injury may be significant in determining the duration of the disability and the costs incurred by the company.

As discussed in a paper entitled "The Control of Low Back Disability: The Role of Management" by Snook (*39*), management often does not respond properly when a worker experiences a back injury. The injured worker may be accused of malingering either by direct accusation or through innuendo. This, in turn, causes the worker to look for ways to get back at management. As such adversary situations develop, the costs of the injury may significantly increase for both the worker and management. However, as discussed by Snook (*39*), studies have indicated that enlightened management can often reduce and perhaps even prevent the disability associated with back injuries through a program that includes positive acceptance of low-back pain, early intervention, good communication and followup, and early return-to-work programs.

Positive Acceptance of Low-Back Pain by Management

The most appropriate response by a supervisor to a back injury experienced by one of his or her workers is to show concern for the needs of the employee and to avoid making rash judgments and setting up adversary relationships because of the injury. Such judgments are usually incorrect and may serve to make the situation worse than it should be. Instead, management should be trained to realize that a certain number of back injuries are likely to occur and should be taught to respond in an appropriate manner when they do occur. The supervisor should encourage the worker to seek immediate medical treatment and (if possible) adapt the workplace or modify the task so that the employee can continue to work on the job. One company that instituted a policy of positive acceptance of low-back pain immediately and dramatically reduced their worker compensation costs. Over a 3-year period, costs were reduced from over $200,000 per year to about $20,000 per year (*39*).

Early Intervention

One key feature of the program described above was that all workers complaining about low-back pain were immediately referred to the company clinic for treatment—even those with minor complaints. Treatment was given during work time by the company nurse. This treatment consisted of heat applications and nonprescription analgesic or anti-inflammatory drugs such as aspirin. During the treatment sessions, worker education was initiated on a one-to-one basis. The education program consisted of basic spinal anatomy and physiology, the expected results from the treatment regimen, proper posture, and suitable exercises. Light-duty work and rest periods were provided by management to the injured employee. If the initial in-house treatment was ineffective, the worker was referred to the company physician for further medical treatment. The physicians were familiarized with the physical demands of the jobs at the company in order to place injured workers in appropriate job positions.

Because this company encouraged the reporting of all episodes of low-back pain (even minor cases), it is not surprising that the number of cases reported actually increased. However, the amount of lost time due to back injuries was significantly reduced. This indicates that the workers were able to stay on the job and did not rely on outside practitioners for treatment, thus reducing the company's cost due to low-back pain.

Followup and Communication

When workers do become temporarily disabled, it is important that management establish and maintain good communications with the worker and appropriate medical personnel. Supervisors should be instructed to follow up every disability case with a telephone call or visit before 2 days of lost time have elapsed. The purpose of the call is to let the worker know that the company is concerned and to inform the supervisor of the status of the worker's recovery.

One company recently instituted a program that increased the communication between the worker, employer, medical practitioner, and insurer (*39*). When a worker compensation claim was received, the employer made immediate contact with the worker and insurer and followed up with calls at regular 10-day intervals to make

certain that the claim was progressing smoothly. The possibility of retraining was explored for extended claims, and a liaison was established between management and the insurer if a gradual return to work was indicated. The focus of all communications was that every action taken was in the best interest of the worker. This program significantly reduced the proportion of long-term worker compensation claims and also significantly reversed a trend of increasing accident rates (*39*).

Early Return-to-Work Programs

The data from several studies have shown that the longer a worker is off from work because of a back injury, the less likely the worker will return to productive employment. These studies underscore the importance of providing modified, alternative, or part-time work to the injured employee to facilitate a quick return to the job. Unfortunately, management often extends the period of disability by requiring workers to be fully recovered before returning to work, which can be a costly policy. Because there appears to be a limited amount of time to act before losing control of the disability and the claim, efficient management should do everything in its power to encourage the worker's timely return to work. Data indicate that an early return to work is in the best interests of everyone: the worker, the company, and the union. In this regard, it may benefit both the company and the union to ensure that work rules in the current contract do not interfere with early return-to-work programs.

SUMMARY

A common complaint of management is that the high costs of back injuries are the result of dissatisfied workers, ineffective medical personnel, and activist unions. However, management must also share in the responsibility when it does not respond appropriately to low-back injuries. The examples cited above indicate that there is a substantial amount that management can do to control the high costs associated with back injuries through improving worker fitness, positive acceptance of low-back pain, early intervention measures, improved followup and communication procedures, and early return-to-work programs. Back injuries may not be entirely preventable at the present time, but there is evidence that management can effectively reduce the costs associated with low-back injuries.

CHAPTER 6.–SUMMARY OF RECOMMENDATIONS

This report has described methods that may be used to reduce the costs and incidence of back injuries in low-seam coal mines. The primary intent of the report was to demonstrate that workers' risk of experiencing back injuries and other musculoskeletal injuries can be reduced through ergonomic redesign of underground materials-handling tasks. These methods have been successful in reducing injury costs in other industries, and if correctly implemented, they can do the same in underground coal mines. Several examples of successful redesign strategies have been provided. The model illustrated in figure 1 has been presented as a guideline that can be used in evaluating and improving current materials-handling practices in low-seam coal mines. This chapter briefly reviews the procedure for redesigning materials-handling tasks as outlined in figure 1.

The first step in improving a mine supply-handling system is to examine the current materials-handling practices in detail (see figure 2). Dependable data need to be collected that identify both favorable and inappropriate supply-handling strategies currently being used at the minesite. For redesign purposes, it is necessary to focus on identification of materials-handling problem areas in the current system. Two techniques that can be used in this effort are accident analysis and task analysis. A review of past accident records can provide a great deal of insight on current supply-handling problems. Hazardous occupations or tasks can be identified as candidates for job redesign using the techniques described in this report. A task analysis can then be used to document and analyze current work practices, so that appropriate job or task redesign can be performed to minimize injury risk to the worker. Videotape is a particularly useful tool for task analysis, as the analyst can view the worker performing the job in "real" time. A particular concern of the analyst is to minimize the number of times materials (especially heavy materials) have to be manually lifted. Greater detail on accident and task analysis is found in chapter 1.

Chapters 2 and 3 of this report describe alternative strategies that can be used to more safely handle materials in low-seam coal mines. To the extent possible, jobs should be redesigned with an emphasis on constructing an efficient and integrated materials-handling system; in other words, a systems approach to materials-handling should be developed. The benefits of instituting a systems approach may include improved coordination with suppliers, fewer delays in mine operation, higher equipment utilization, better scheduling, fewer materials lost because of breakage, and safer, more systematic work procedures.

The two best redesign alternatives for manual materials-handling chores are task elimination and using a mechanical-assist device to perform the task. These methods significantly reduce the number of times materials are manually lifted and thus provide the greatest potential for preventing musculoskeletal injuries. Careful examination of the current supply-handling system will probably identify several tasks that can be eliminated, reduced, or combined to improve the flow of supplies. Eliminating unnecessary tasks not only improves efficiency and economy of the system, it also greatly reduces the risk of worker injury by reducing their exposure to hazardous lifting conditions.

If task elimination is not possible, the next best redesign solution is to have a mechanical-assist device perform the lifting task. With good planning, it is often possible to handle supplies almost entirely through mechanical means. A common flaw in supply systems of many mines is that supplies are delivered on pallets or in unit loads only to be broken apart on the surface, necessitating considerable manual lifting. One problem experienced in low-seam coal mines is that traditional mechanical-assist devices (such as forklifts, cranes, or hoists) cannot be used because of the restrictive roof height. However, Bureau research has demonstrated that task-specific mechanical assists can be developed at fairly low expense. Many such devices (which are described in chapter 2) can be fabricated in a well-equipped mine shop.

Unfortunately, not all materials-handling tasks can be eliminated or mechanized. When manual lifting is necessary, the lifting task should be designed so that the worker's physical capabilities are not exceeded. Recent Bureau research has shown that the postures that low-seam coal miners must adopt to perform lifting tasks may significantly limit the amount of weight that can be safely lifted. For instance, in a kneeling posture, a miner's lifting capacity is approximately 18 pct lower than in a stooping posture. Data from Bureau lifting capacity studies indicate that for compact, repetitively handled loads (such as rock dust bags, ventilation stopping blocks, and crib blocks), 55 lb is the maximum recommended weight in the stooped posture and 45 lb is the maximum recommended weight in the kneeling posture. Because all low-seam mines require significant periods of lifting in kneeling posture, it is suggested that supplies be designed in accordance with the reduced lifting capacity of miners in the kneeling posture. Additional recommendations for manual lifting in low-seam mines are provided in chapter 3.

While the three redesign strategies described above will probably have the greatest impact in reducing the threat of worker injury, other methods can be used to reduce injury risk. These techniques include worker selection and worker training. Worker selection usually includes evaluation of one or more of the following: physical strength, aerobic capacity, or a clinical evaluation of the individual. The test or tests administered need to be directly related to the demands of the job to prevent accusations of discriminatory selection procedures (*32-33*). Worker training may be considered if none of the previous methods can be used. Unfortunately, training does not appear to be as effective in controlling injuries as those described earlier. A training program on manual lifting should include the following topics: risks of unsafe materials handling, basic anatomy and biomechanics of lifting, use of mechanical-assist devices, and accident avoidance. Active involvement of the worker is crucial to the success of the program (*34*). These injury control methods are described in greater detail in chapter 4.

Once the appropriate redesign strategy has been chosen, the new strategy must be implemented. This step may be the most important determinant of the success of the redesign program. Many redesign strategies may fail, not because of a flawed concept, but because of poor implementation practices. The new strategy may be developed by management, but it is the miners who ultimately determine how well the new plan will work. If the miners are hostile toward the redesign strategy, proper implementation of the plan will be difficult. Active communication between management and labor is an important consideration during this phase and will improve the chances of successful implementation of the new work practices.

Evaluation of the newly developed materials-handling strategy is another crucial step in the process of redesigning the system. Occasionally, the strategy put into effect may overlook important, unintended consequences. It is not unusual for a strategy to have an effect that was not calculated or anticipated, though these effects may not always be negative (*35*). Therefore, it is crucial to get feedback on how well the changes are working and how well the miners are accepting the new procedures. The evaluation phase should not only address how well the procedure has reduced injury risk but also consider how the new strategy has affected other aspects of the working environment. Implementation and evaluation of the redesign strategy are discussed in chapter 4.

Management must realize that not all back injuries will be preventable. However, a policy that encourages a prompt return to the workplace is sure to have a large positive influence on worker welfare and on the costs incurred by the company. Enlightened management can reduce or even prevent disability associated with back injuries through a policy that includes positive acceptance of low-back pain, early intervention strategies, good communication and followup procedures, and early return-to-work programs (*39*). Details of such a policy are described in chapter 5.

Compared with most industrial settings, low-seam coal mines present relatively unique barriers to using proper lifting techniques or achieving mechanical transfer of materials. However, the rapid emergence and continued development of the field of ergonomics provides mines with new and innovative solutions that can be used to reduce the costs and incidence of back injuries. Risk of back injury can be reduced through proper design of jobs and matching the job demands to the capabilities of the underground worker. This report has recommended practices for handling materials in low-seam coal mines. Methods have been provided to examine and redesign current supply-handling systems to reduce the threat of back injury. The strategies contained in this report, if correctly implemented, can significantly reduce the cost and incidence of materials-handling injuries in low-seam coal mines.

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